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EUROPEAN REFUSE FIRED ENERGY SYSTEMS

EVALUATION OF DESIGN PRACTICES

The Hague Refuse Fired Power Plant
The Hague, Netherlands

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Volume 10

U.S. ENVIRONMENTAL PROTECTION AGENCY

1979

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An environmental protection publication (SW-176c.10) in the solid waste management series.

TRIP REPORT

to

THE HAGUE REFUSE-FIRED POWER PLANT
THE HAGUE, NETHERLANDS

on the contract

EVALUATION OF EUROPEAN REFUSE-FIRED
STEAM GENERATOR DESIGN PRACTICES

September 14, 15, 16, 1977

to

U.S. ENVIRONMENTAL PROTECTION AGENCY

EPA Contract No. 68-01-4376
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January 20, 1978

by

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1.C

PREFACE

This trip report is one of a series of 15 trip reports on European waste-to-energy systems prepared for the U.S. Environmental Protection Agency. The overall objective of this investigation is to describe and analyze European plants in such ways that the essential factors in their successful operation can be interpreted and applied in various U.S. communities. The plants visited are considered from the standpoint of environment, economics and technology.

The material in this report has been carefully reviewed by the European grate or boiler manufacturers and respective American licensees. Nevertheless, Battelle Columbus Laboratories maintains ultimate responsibility for the report content. The opinions set forth in this report are those of the Battelle staff members and are not to be considered by EPA policy.

The intent of the report is to provide decision making information. The reader is thus cautioned against believing that there is enough information to design a system. Some proprietary information has been deleted at the request of vendors. While the contents are detailed, they represent only the tip of the iceberg of knowledge necessary to develop a reliable, economical and environmentally beneficial system.

The selection of particular plants to visit was made by Battelle, the American licensees, the European grate manufacturers, and EPA. Purposely, the sampling is skewed to the "better" plants that are models of what the parties would like to develop in America. Some plants were selected because many features envolved at that plant. Others were chosen because of strong American interest in co-disposal of refuse and sewage sludge.

The four volumes plus the trip reports for the 15 European plants are available through The National Technical Information Service, Springfield, Virginia 22161. NTIS numbers for the volumes and ordering information are contained in the back of this publication. Of the 19 volumes only the Executive Summary and Inventory have been prepared for wide distribution.

ORGANIZATION

The four volumes and 15 trip reports are organized the the following fashion:

VOLUME I

A EXECUTIVE SUMMARY
B INVENTORY OF WASTE-TO-ENERGY PLANTS
C DESCRIPTION OF COMMUNITIES VISITED
D SEPARABLE WASTE STREAMS
E REFUSE COLLECTION AND TRANSFER STATIONS
F COMPOSITION OF REFUSE
G HEATING VALUE OF REFUSE
H REFUSE GENERATION AND BURNING RATES PER PERSON
I DEVELOPMENT OF VISITED SYSTEMS

VOLUME II

J TOTAL OPERATING SYSTEM RESULTS
K ENERGY UTILIZATION
L ECONOMICS AND FINANCE
M OWNERSHIP, ORGANIZATION, PERSONNEL AND TRAINING

VOLUME III

P REFUSE HANDLING
Q GRATES AND PRIMARY AIR
R ASH HANDLING AND RECOVERY
S FURNACE WALL
T SECONDARY (OVERFIRE) AIR

VOLUME IV

U BOILERS
V SUPPLEMENTARY CO-FIRING WITH OIL, WASTE OIL AND SOLVENTS
W CO-DISPOSAL OF REFUSE AND SEWAGE SLUDGE
X AIR POLLUTION CONTROL
Y START-UP AND SHUT-DOWN
Z APPENDIX

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The authors are greatly indebted to the above experts for their very helpful assistance in gathering the information for this trip report.

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SUMMARY

The Hague plant, ten years old, is unique among large plants (1440 t/d) in that the four furnaces are not water cooled. This feature was a natural result of the original design assumption that the plant, handling no industrial refuse, would receive relatively wet refuse with a low heat value (1800 kcal/kg) [3240 Btu/lb] [7535 kJ/kg]. However, over the nearly ten years of operation, the refuse heat value has increased causing wall-slagging problems.

From the beginning, boiler wall-tube and superheater corrosion has been a problem requiring significant maintenance in the first three units, which started up in 1968. However, in Unit 4, started in 1971, a drastic modification of superheater design and location has prevented significant corrosion there to date. Also, in the first three units, partial refractory covering of the radiation pass wall tubes and reduced firing rates have nearly eliminated tube wastage.

The plant is operated as a 23 Mw electrical production component of a municipal energy facility dominated by a 200 Mw oil-fired plant which also serves a district heating network. At present, the waste plant turbines operate condensing but some thought is being given to modify the turbines so as to make the exhaust heat available for district heating.

STATISTICAL SUMMARY

Community description:	
Area (square kilometers)	70
Population (number of people)	550,000
Key terrain feature	Flat, coastal
Solid waste practices:	
Total waste generated per day (tonnes/day)	575
Waste generation rate (Kg/person/day)	1.14
Lower heating value of waste (Kcal/kg)	1800 - 2300
Collection period (days/week)	5
Cost of collection (local currency/tonne)	
Use of transfer and/or pretreatment (yes or no)	No
Distance from generation centroid to:	
Local landfill (kilometers)	4
Refuse fired steam generator (kilometers)	0
Waste type input to system	Residential
Cofiring of sewage sludge	No
Development of the system:	
Date operation began (year)	1968
Plant architecture:	
Material of exterior construction	steel
Stack height (meters)	100
Refuse fired steam generator equipment:	
Mass burning (yes or no)	Yes
Waste conditions into feed chute:	
Moisture (percent)	35%
Lower heating value (Kcal/kg)	1800 - 2300

Volume burned:	
Capacity per furnace (tonnes/day)	1,440
Number of furnaces constructed (number)	4
Capacity per system (tonnes/day)	1,440
Actual per furnace (tonnes/day)	360
Number of furnaces normally operating (number)	3
Actual per system (tonnes/day)	1,080
Use auxiliary reduction equipment	No
Pit capacity level full:	
(tonnes)	10,000
(m^3)	
Crane capacity: (two)	
(tonnes)	10 each
(m^3)	4 each
Feeder drive method	mechanical, vibrating
Burning grate:	
Manufacturer	Von Roll
Type	3-step, sloping, recipro.
Number of sections (number)	3
Length overall (m)	13, 14.5
Width overall (m)	3
Primary air-max (Nm^3/hr	71,000
Secondary air-overfire air-max (m^3/min)	350
Furnace volume (m^3)	
Furnace wall tube diameter (mm)	63.5
Furnace heating surface (m^2)	
Auxiliary fuel capability	No
Use of superheater	Yes
Boiler	
Manufacturer	Bronswerk
Type	Eckrohr - (corner-tube)
Number of boiler passes (number)	3

Steam production per boiler (kg/hr)	3 x 37,000 1 x 41,500
Total plant steam production (kg/hr)	125,500
Steam temperature (° C)	425
Steam pressure (bar)	40
Use of economizer	Yes
Use of air preheater	Yes
Use of flue gas reheater	No
Cofire (fuel or waste) input (verbal)	No
Use of electricity generator	Yes
Type of turbine (verbal)	
Number of turbines (number)	2
Steam consumption (kg/hr)	
Electrical production capacity per turbine (kw)	11.5 mw each
Total electrical production capacity (kw)	23,000
Turbine back pressure	
User of electricity ("Internal" and/or "External")	Both
Pollution control:	
Air:	
Furnace exit conditions	
Gas flow rate (m^3/hr)	89,000
Furnace exit loading (mg/Nm^3)	(1-3)55/(4)19

OVERALL SYSTEM SCHEMATIC

Figure 9-1 is an artist's sketch of the overall system. Bulky refuse is delivered at the upper left and is processed for the furnaces. Community refuse arrives at the right. Ash and residue is removed for processing at the lower left and electricity leaves at the lower right for the G.E. (Gemeentelijk Energiebedrijf) [The Community Energy System which supplies fuel gas, electricity, and district heating for the Hague and its suburbs].

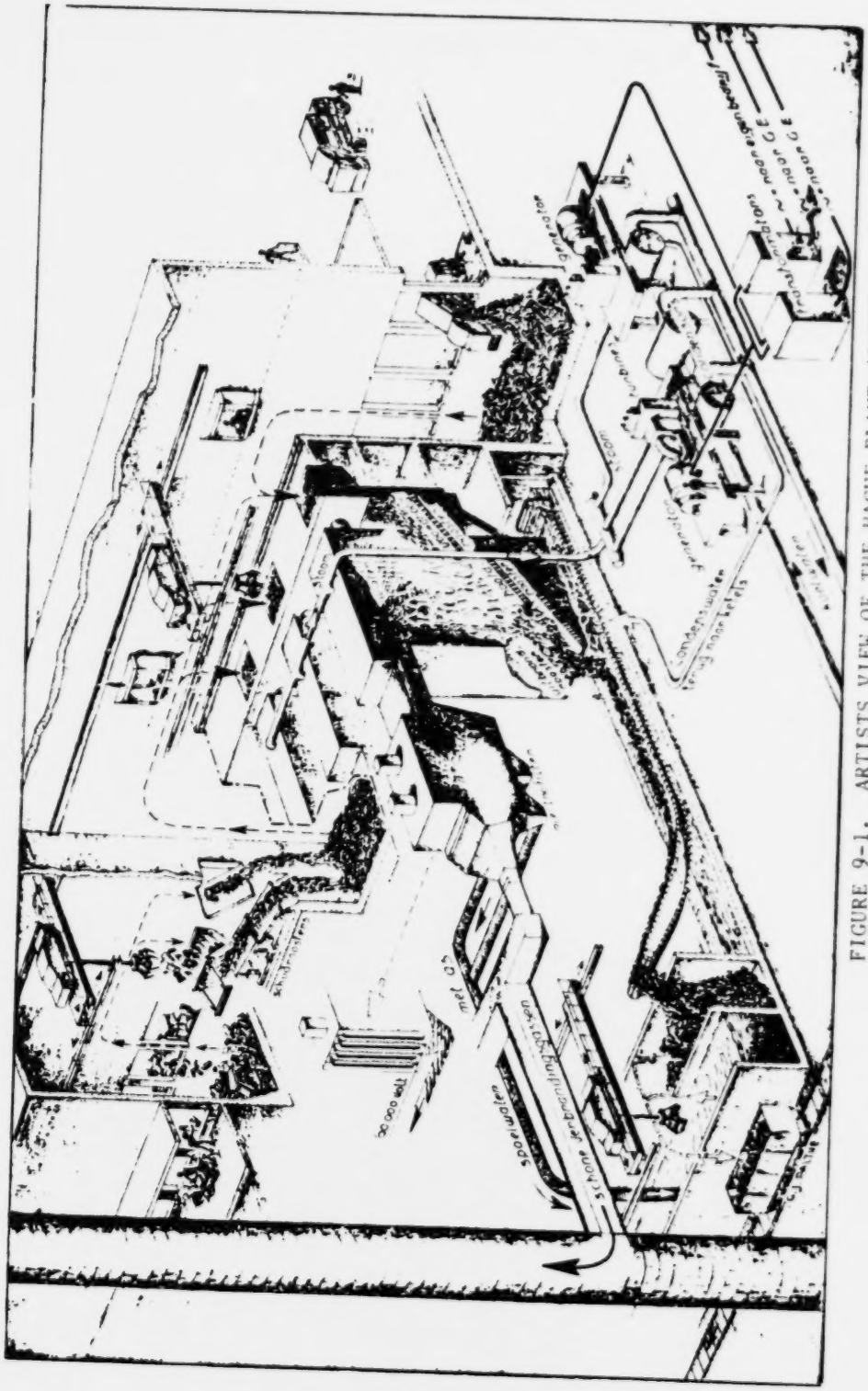

FIGURE 9-1. ARTISTS VIEW OF THE HAGUE PLANT (COURTESY GEMEENTELIJK ENERGIE BEDRIJF VUILVERBRANDING)

COMMUNITY DESCRIPTION

Geography

The Hague is situated on the North Sea on very flat coastal land.

The plant, located in the southwest part of The Hague, is completely surrounded by old residential communities. The plant is adjacent to a large oil-burning municipal power plant and is less than one km (0.6 mi) from the International Peace Palace. Figure 9-2 shows the concentrated urban location of the plant.

A population of 550,000 is served: 500,000 of these in The Hague and 50,000 in four small neighboring communities. The population served in 1968 was 450,000 when the plant was built. At present the population of The Hague is not growing, but is decreasing slightly, and the annual tonnage of refuse received has about stabilized around 210,000 tonnes per year (231,000 t/y). The collection area for this plant extends over a radius of about 15 km (9.3 mi) from the plant.

Industry and Government

There is no heavy industry. The city is a government center and, because of its location on the sea, is also visited by many tourists during the summer.

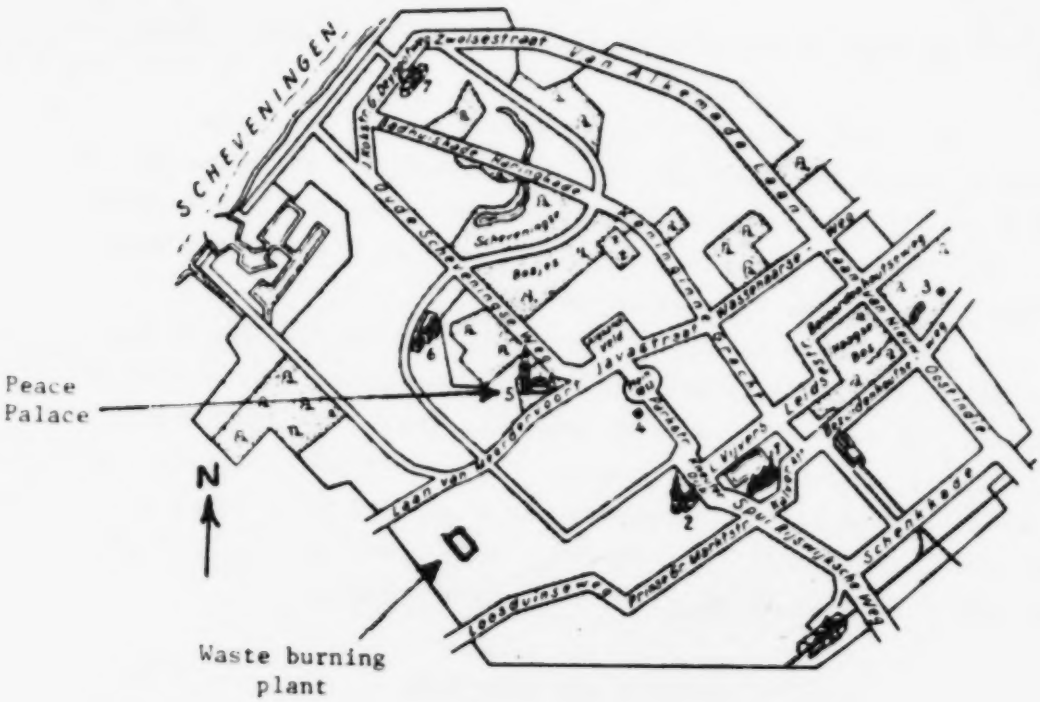

FIGURE 9-2. MAP OF CENTRAL CITY OF THE HAGUE SHOWING THE WASTE BURNING PLANT AND INTERNATIONAL PEACE PALACE NEAR CENTER. THE STRAND (NORTH SEA BEACH) IS LESS THAN 2 KM (1.2 MI) NORTHWEST OF THE PLANT AT THE RESORT OF SCHEVENIGEN.

SOLID WASTE PRACTICES

Solid Waste Generation

The plant receives little industrial waste. Chemical wastes are sent to the Botlek plant at Rotterdam, which has a rotary kiln specifically for chemical wastes. Along with typical community refuse, The Hague plant receives much government waste paper and some boxes from department stores. Figure 9-3 shows the curve of annual refuse generation.

Solid Waste Collection

There are 55 municipal packer trucks which collect twice per week on weekdays except Wednesday when the crews are assigned to bulky refuse pickup. They do this in two alternate sections of town on alternate Wednesdays, using open trucks.

Private haulers also deliver refuse to a separate bunker and pay cash for the privilege on a weight basis. If a load is mostly metallic, such as appliances, it is placed in a collection yard at the plant for later processing by a new residue processing plant, privately operated.

Solid Waste Transfer or Pretreatment

There is no transfer or pretreatment of waste before it reaches the plant. There have been some experiments with separate collection of glass but the results were that most of those participating preferred not to separate.

Solid Waste Disposal

Non-combustibles and incinerated residue goes to a sanitary landfill at Rijswijk, about four km (2.5 mi) south of The Hague plant. No household refuse goes directly to the Rijswijk landfill.

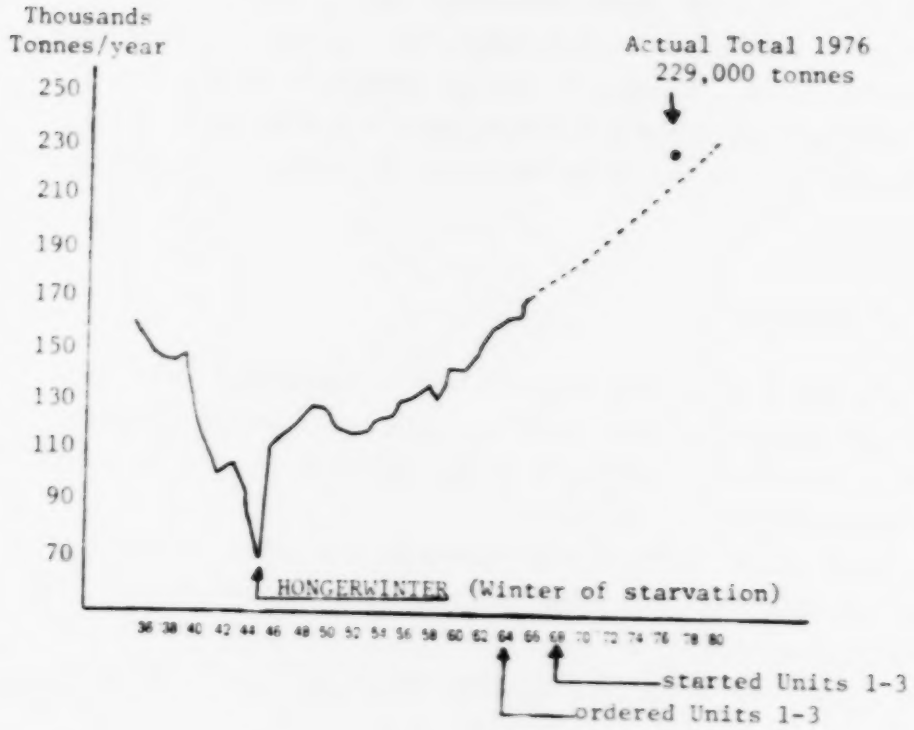

FIGURE 9-3. ANNUAL REFUSE GENERATION IN THE HAGUE SINCE 1936[1]

For six years the incinerated residue was used to build dikes for land reclamation but this was stopped because of concern over increased cadmium and silver content of local drinking water.

Very recently, August 1977, a private contractor began a resource recovery processing system for the plant residue at the plant property.

Table 9-1 shows the monthly refuse receipts at The Hague plant in 1976.

TABLE 9-1 . REFUSE RECEIVED AND RESIDUE PRODUCED AT THE HAGUE PLANT, 1976, TONNES

1976 Month	Household Refuse	Bulky and Misc. Deliveries	Total from The Hague	Total from 4 adjacent Communities	Metal Scrap	Grate Residue and Flyash
January	11,229	5,150	16,379	1,601	106	6,583
February	9,973	5,044	15,017	1,473	46	5,966
March	11,879	5,961	17,840	1,791	100	7,357
April	11,278	5,586	16,864	1,715	79	7,007
May	11,981	5,676	17,657	1,748	141	7,702
June	12,297	5,868	18,165	1,783	223	7,645
July	10,623	5,183	15,806	1,608	134	6,299
August	11,799	5,655	17,454	1,715	115	7,079
September	12,273	5,887	18,160	1,762	103	7,098
October	12,313	5,959	18,272	1,775	97	6,913
November	12,535	6,515	19,050	1,774	122	7,361
December	12,217	6,305	18,522	1,744	95	6,907
TOTAL	140,397	68,789	209,186	20,489	1,361	83,917

DEVELOPMENT OF THE SYSTEM

In 1919, the city built an incinerator but it was met by a storm of protest by those favoring utilization of wastes for recovery of land. As a result, on June 18, 1929, an agreement was reached whereby the incinerator continued to operate at a low rate but a distant landfill site was selected.

Later, for over 30 years, before the present plant was contracted for in November 1964, refuse from The Hague was sent by rail to a landfill and compost plant at Wijster in the region of Drente, 200 km (120 mi) away in the northeast part of Holland. Other cities, such as Amsterdam also sent refuse to Wijster, which had the largest compost plant in Holland. Much of the compost was sold in five and ten kg (11 to 22 lb) sacks. The dedicatory brochure for The Hague plant, published in March 1968, stated that from the opening of the Wijster site on February 23, 1932, until the end of 1967, 154,984 rail car loads of refuse from The Hague were shipped to Wijster.

However, the cost of the long rail haul increased over the years and the demand for compost for land reclamation decreased. Accordingly, a study was begun on alternate methods for refuse disposal. In 1958, the conclusion was reached that a modern waste-burning facility should be planned. The planning extended from 1960 through 1964 in cooperation with the "Gemeentelijk Energiebedrif" (municipal utilities). One of the principal considerations was the need to meet high hygienic standards and to avoid nuisance factors inherent in other solutions. At the time when the decision was made, fuel prices were high, and the possibility to recover heat energy from refuse promised attractive revenues. This led to the combination of combustion and power generation. The final plant design included a total of four furnace-boiler units with an incineration capacity of 360 tonnes/day (400 tons/day) each. In November 1964, the order was issued for three of them. The first three began operation in January 1968.

PLANT ARCHITECTURE

The plant, shown in Figure 9-4, presents a clean and impressive facade to the residential area which is very close. It stands on the site of a former gasworks - hence, the street address: Gaslaan. An older and larger 200 mw municipal power plant stands adjacent to this plant. The two plants are separated by the Afvoer Canal and a busy street railway line.

The structure is steel, enclosed in coated aluminum panels. The tallest portion is 29 m (95 ft) tall. The main structure is 47.72 m (156 ft) and 46.45 m (152 ft) deep.

Generously sized roadways on the plant property provide room for trucks to line up without affecting traffic on the surrounding streets. This is an old gasworks site and there is no landscaping. Several of the old gasworks service building are now shops for the refuse plant.

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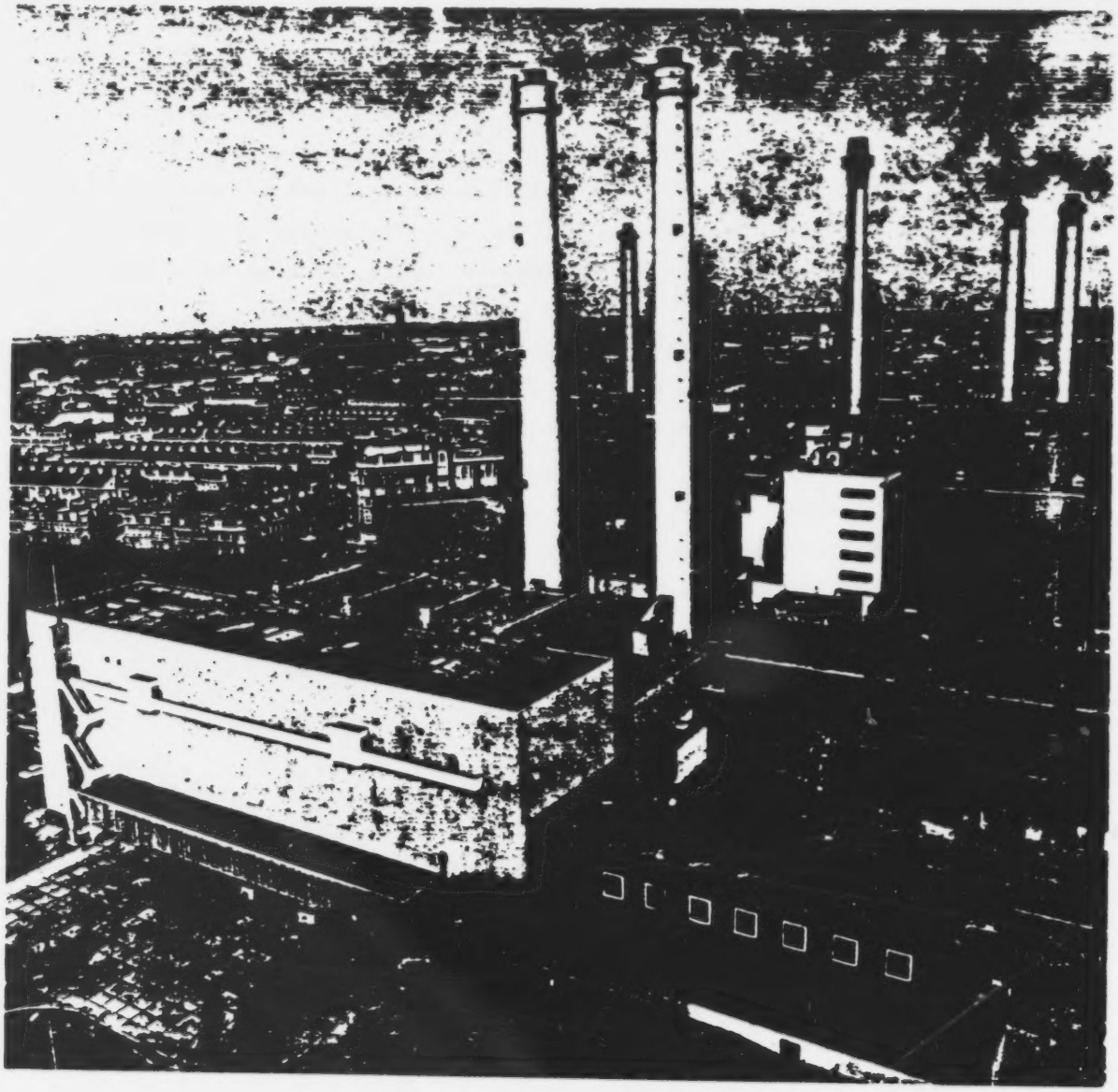


FIGURE 9-4. THE HAGUE PLANT SITUATED NEAR THE CENTER OF THE HAGUE. THE FOUR CHIMNEYS IN THE BACKGROUND SERVE THE 200 MW OIL-FIRED MUNICIPAL POWER PLANT (Courtesy GE Vuilver-branding)

REFUSE-FIRED STEAM GENERATOR

Waste Input

Since The Hague is not a highly industrialized community, this plant receives very little industrial refuse. The supply of refuse is principally residential plus some commercial waste, such as boxes and much governmental paper.

Figure 9-5 shows the seasonal variations in lower heat value and moisture content of the local refuse as measured in 1964-65,[1] when the annual average lower heat value was only about 1800 kcal/kg (3240 Btu/lb) [7535 kJ/kg]. However, as with all European refuse, the heat value has been increasing, so that in 1972-73 at The Hague, it reached 2300 kcal/kg (4140 Btu/lb) [9630 kJ/kg]. However, during the oil embargo in 1973-74, apparently many of the citizens found ways to recover heat by burning some of their dry combustible wastes and the heat value of the waste delivered to the plant dropped to about 1800 kcal/kg. An analysis of a refuse sample during that period produced the following:

Carbon	7%
Volatile	34%
Ash	24%
Moisture	35%
Heat Value	1800 kcal/kg (3240 Btu/lb)

However, in 1976-77 the heat value had again reached 2300 kcal/kg. The furnaces in Units 1-3 were designed for a maximum heat value of 2066 kcal/kg (3270 Btu/lb) [8,653 kJ/kg]. However, some dry, bulky waste such as wooden crates and cardboard boxes can have much higher heat value, up to 4000 kcal/kg (7200 Btu/lb [16,750 kJ/kg], and wetting of such refuse to protect the furnaces and boilers will be discussed later. Unit 4 was designed for a heat value of 2500 kcal/kg (4500 Btu/lb [10,467 kJ/kg].

There are 55 city trucks which deliver refuse eight hours per day, 8:00 a.m. to 4:00 p.m., five days per week. Also, the plant accepts deliveries by private trucks. An estimated 20-30 percent of the total of approximately 210,000 tonnes/yr (231,000 tons/yr) is delivered by private haulers who pay cash on a weight basis.

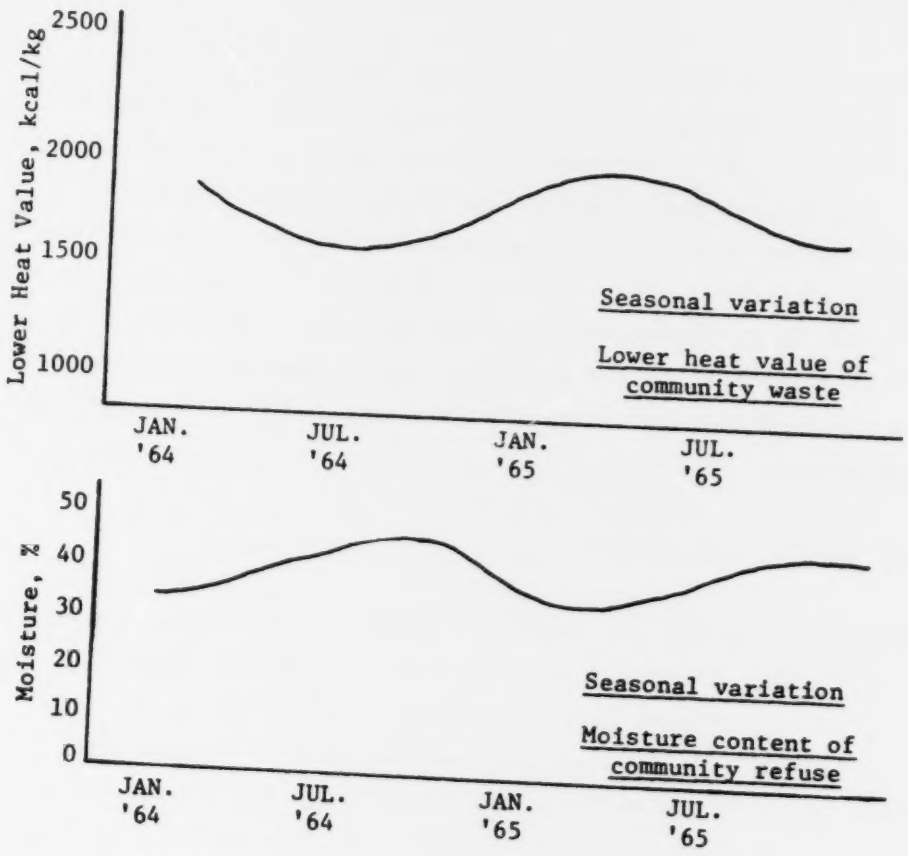


FIGURE 9-5. SEASONAL VARIATION OF LOWER HEAT VALUE AND MOISTURE CONTENT OF REFUSE AT THE HAGUE, 1964-65(1)

Normally the plant operates 5-1/2 days per week and normally only three of the four furnaces are operating. Startup time is usually 3:00 p.m. on Sunday and operation continues until about 8:00 a.m. Saturday.

Weighing Operation

The weigh station is not operated by the plant. Instead, it is operated by the municipal waste collection department. In 1976, the station was relocated and modernized. It is situated between two scales, one for city trucks, one for private. The scale operator regulates traffic flow by means of a manually controlled red-green signal light on the approach to the scale house. Private trucks weigh in and then out. City trucks weigh in by insertion of a coded magnetic card into a slot at the scale which identifies the truck and causes immediate machine recording of the loaded weight, known tare weight, and by difference the net weight delivered.

Provisions to Handle Bulky Wastes

This plant is unusual in that it has two bunkers: a large one of about 10,000 m^3 (13,080 yd^3) capacity (level full) for community refuse which, with the hinged lift type doors, can be piled up to about 16,000 m^3 (20,930 yd^3) , plus a smaller one for private haulers which often receives mainly bulky refuse. The two bunkers were shown earlier in the upper left and right center of Figure 9-1. The tendency for the privately delivered refuse in the smaller bunker to be very dry and highly combustible is so great that water sprays located high on the bunker wall are turned on much of the time to keep that waste dampened.

Figure 9-6 shows a private hauler delivering very dry, bulky waste.

Where the scale operator observes non-combustible bulky waste, such as steel appliances being delivered, he directs the driver to unload the objects in a walled-in yard near the new waste processing facility for later processing and reclamation and disposal.

FIGURE 9-6. PRIVATE HAULER DELIVERING VERY DRY BULKY WASTE TO THE HAGUE PLANT (Battelle Photograph)

The original plant design included a 15 tonne/hr Von Roll shear shown earlier in the upper left of Figure 9-1. This shear received bulky waste from the small bunker which receives primarily bulky waste from private haulers. However, owing to the light construction of this early shear design, much maintenance was required. Also, some explosions were experienced within the shear. Accordingly, in 1970 the use of the shear was discontinued and the crane operators are instructed to try to smash bulky objects in the bunker by dropping the crane bucket on them. Also, as shown near the upper center of Figure 9-1, there is a holding pit which is positioned to receive either sheared material or bulk refuse that can be by-passed over the shear. From that pit, the operators of the main bunker cranes can lift refuse directly to the furnace hoppers or it can be deposited in the main bunker for mixing with conventional refuse. This complex arrangement requires good judgment and skill on the part of the crane operators to assure a well-mixed and reasonably sized supply of refuse to the four furnaces.

If four of the main bunker doors are closed, the estimated storage capacity is about 4500 tonnes (4950 tons) which is nearly one week's supply for three furnaces.

There are two crane control rooms high on the outside of the main bunker wall controlling two cranes. Usually only one crane operates at a time. The smaller bunker is served by one crane controlled by an operator riding the crane in a cab. Each of the main cranes, made by Heemat of Holland, is of nine tonne capacity carrying a polyp-type bucket of 4 m^3 each. Fire control in the main bunker is by both fire hose and fixed water spray. To obtain a measure of firing rate, the operators record the number of buckets charged to each furnace per hour.

Furnace Hoppers and Feeders

Figure 9-7 shows a cross-section of boiler/furnaces 1-3 which were built in 1967. Each of the four furnace hoppers has a top opening of five by 3.7 m (16.4 by 12.1 ft). Immediately beneath the hopper is a large vibrating feeder which feeds into a water-cooled chute about 3.4 by

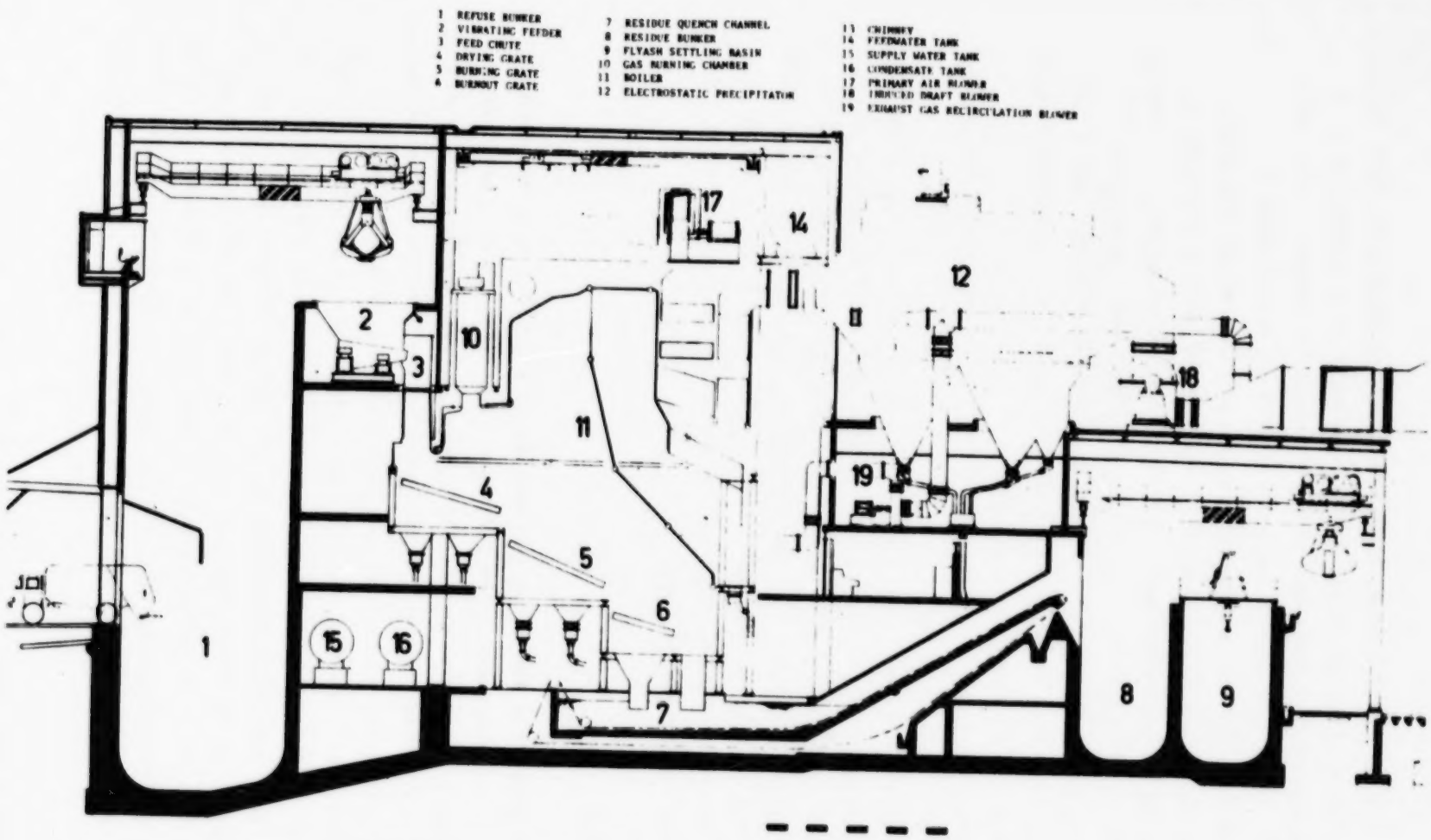


FIGURE 9-7. CROSS-SECTION OF BOILER SYSTEMS, 1-3 THE HAGUE
(Courtesy of Gemeentelijke Reinigindienst)

1 m (11 by 3.3 ft). The feeder, made by Schenck of Darmstadt, West Germany, is vibrated by rotating eccentric weights automatically controlled by a radioactive chute-level indicator made by Endress and Hauser. The radioactive source is Cesium 37 with an intensity of 75 milliroentgens.

Burnback in the chute never occurs on start-up or shut-down, only if the chute jams, preventing full flow or refuse. A flap damper can be used to seal off the top of the chute in case of burnback. Jamming in a hopper can be released by the force of a railroad tie dropped in by the bucket. The vibrating feeders have been trouble-free for nearly ten years. It is expected that the steel floor-plate of the feeders will need replacement after about 12 years of service.

Figure 9-8 shows a polyp bucket in the act of dropping a charge into a furnace hopper opening.

Figure 9-9 shows a mirror positioned above the furnace hopper to provide the crane operator with a view of the inside of the hopper so that he can know when the hopper has been emptied by the vibrating feeder.

Figure 9-10 shows, in the background, one of the two crane control cabins on the bunker wall. In the foreground an empty hopper with a portion of the floor plate of the vibrating feeder showing at the bottom of the hopper can be seen.

Burning Grate

Figure 9-11 shows the improved grate which Von Roll has been developing in recent years. The older grate, as installed on all four units at this plant, involves the alternating forward motion of adjacent grate "plates." This naturally caused wear by the abrasive action of ash and clinker particles sifting between the plates as they slide relative to each other. As a result, the air gaps between the grate plates, originally 3 mm (0.12 in) increased in nearly ten years to, in some cases, 40 mm (1.6 in). This has impaired control of the distribution of primary air and, at times, the air-flow resistance through portions of the grate and fuel bed is so low that the air pressure below the grate becomes less than atmospheric. However, there has been little grate repair work done in nearly ten years of operation except for annual renewal of the sliding plates attached to the bottom of the grate bars.

FIGURE 9-8. POLYP BUCKET DROPPING A CHARGE OF MUNICIPAL REFUSE INTO A FURNACE HOPPER AT THE HAGUE PLANT (Battelle Photograph)

FIGURE 9-9. MIRROR ABOVE A FURNACE HOPPER TO ENABLE CRANE OPERATOR TO DETERMINE WHEN THE HOPPER NEEDS TO BE REPLENISHED - THE HAGUE PLANT (Battelle Photograph)

FIGURE 9-10. CRANE OPERATOR'S CABIN AT THE HAGUE PLANT WITH EMPTY FURNACE HOPPER AND A PORTION OF THE FLOOR PLATE OF THE VIBRATING FEEDER IN THE FOREGROUND (Battelle Photograph)

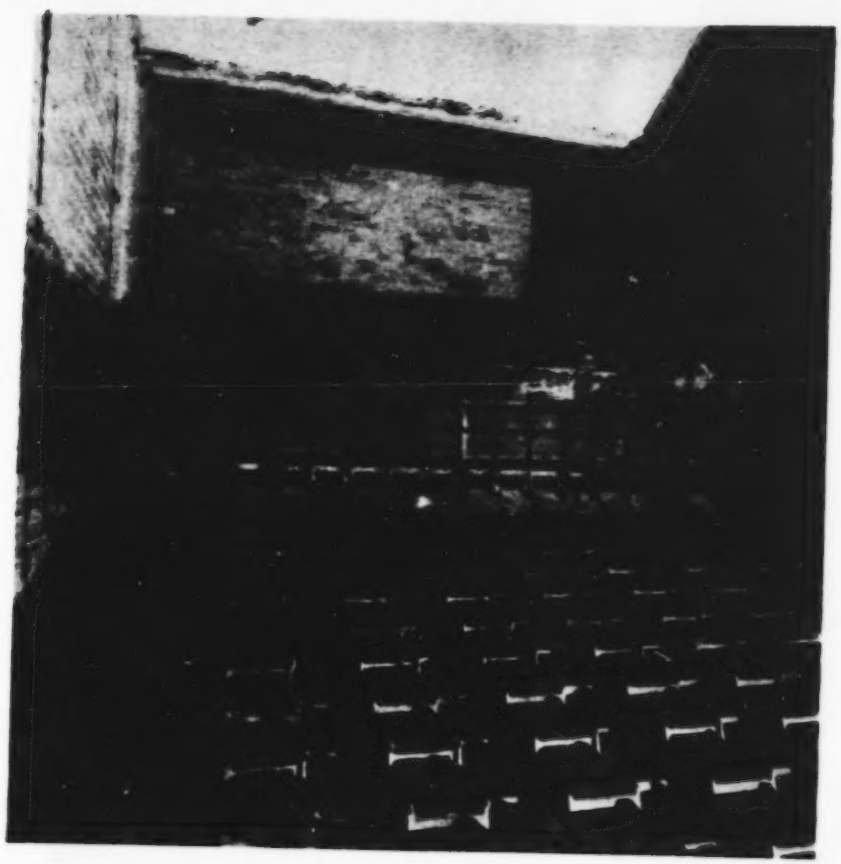


FIGURE 9-11. TWO STEPS OF VON ROLL GRATE USING RECIPROCATING FORWARD-FEED DESIGN. (Courtesy of Von Roll)

For smaller furnaces, that is five tonnes per hour or less, Von Roll began 15 years ago to install the improved grate composed of alternate fixed and moving rows in which each entire moving row of grate plates moves forward and backward together, thus eliminating the relative motion and grinding action between adjacent grate blocks. There is still a wearing action then due to the relative motion of each moving row on the stationary row beneath it, but the air gap there is kept minimal by the gravitational force holding each upper row tightly against the next row below.

Von Roll is now applying this grate as shown in Figure 9-11 to all new furnaces regardless of size. At this plant the grate drive is hydraulic. Some drive failures have occured.

At The Hague No. 2 furnace, after about 55,000 hours operation, is now being converted to use a Künstler grate manufactured by K & K Ofenbau AG, Zurich. This type of grate, shown in Figure 9-12, which has been used in a number of plants, similar to improved Von Roll grate, consists of horizontal rows of grate blocks which are moved forward in unison, thus eliminating relative motion between adjacent blocks. At the same time, the Künstler air wall system has been installed in the walls near the grate. This will be discussed later under Furnace Wall.

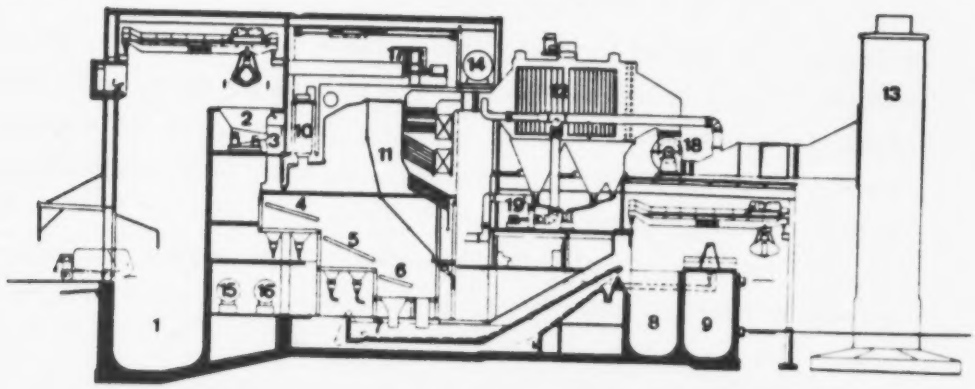
Figure 9-13 shows comparative cross-sections of the two boiler furnace systems at The Hague: Units 1-3 started up in 1968; Unit 4 started up in early 1974.

Primary air is supplied through seven controlled zones under the Von Roll grate for Units 1-3. There are six zones on Unit 4. Initially, this air was preheated as described later. There is a manually set damper controlling flow to each zone. Also, an automatically controlled main damper controls the total supply of air from the blower. Three thermocouples attached to each grate enable indication of grate temperatures in the control room.

As can be seen in Figure 9-13 and also earlier in Figure 9-7, in Units 1-3 there was a large drying grate because it was anticipated that often the refuse would be very wet. Also, directly above the drying grate there was a gas burning chamber so that hot flue gas could be forced directly downward against wet refuse on the drying grate. However, the refuse has not been as wet as expected. Accordingly, in Unit 4 the gas (or oil) burning chamber was eliminated and the size of the drying grate was

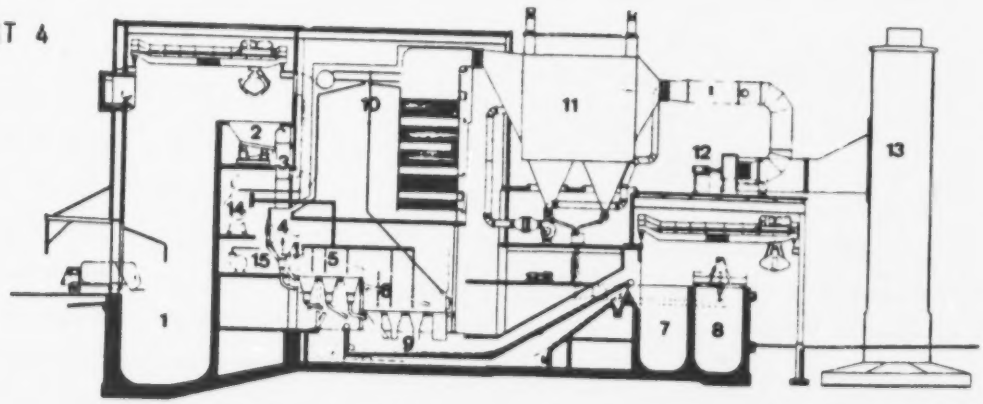
FIGURE 9-12. KÜNSTLER GRATE
(Courtesy of K & K AG)

THE HAGUE UNITS 1, 2, 3 LONGITUDINAL SECTION



1 Refuse pit
2 Vibrating hopper
3 Feed chute
4 Feed grate
5 Main grate
6 Burnout grate
7 Clinker channel
8 Clinker pit
9 Settling tank
10 Combustion chamber
11 Boiler
12 Electrostatic precipitator
13 Stack
14 Feed water tank
15 Additional water tank
16 Condensate tank
17 Forced draft fan
18 Induced draft fan
19 Flue gas recycling fan

THE HAGUE UNIT 4



1 Refuse pit
2 Vibrating hopper
3 Feed chute
4 Feed grate
5 Main grate
6 Burnout grate
7 Clinker pit
8 Settling tank
9 Clinker channel
10 Boiler
11 Electrostatic precipitator
12 Induced draft fan
13 Stack
14 Forced draft fan
15 Overfire air fan

FIGURE 9-13. COMPARATIVE CROSS-SECTIONS OF THE TWO BOILER-FURNACE SYSTEMS AT THE HAGUE PLANT. UNITS 1-3 WERE DESIGNED IN 1965. UNIT 4 WAS DESIGNED IN 1971. (Courtesy of Gemeentelijk Energiebedrijf Vuilverbranding)[Waste-burning Energy Utility]

reduced. The drying or feed grate, Item 4 in Figure 9-13, is seen to be shorter in Unit 4 and the burnout grate, Item 6, is longer. Table 9-1 shows the grate dimensions for all four furnaces. In this table the intensity of utilization or burning rate is seen to be significantly less in Unit 4 than in Units 1-3.

In addition to the grate change, many other improvements can be seen to have evolved during the six years, 1965-1971, that elapsed between the beginning of these two designs.

The residue handling system was unchanged when Unit 4 was built. Each stoker discharges to a concrete quench tank from which the residue is continuously removed by a submerged drag conveyor shown in both parts of Figure 9-13. The conveyor delivers the residue, partially drained, to the residue bunker from which it is lifted by crane into trucks or onto a conveyor leading to the ash recovery process. The same crane serves the adjacent flyash settling tank.

Furnace Wall

In terms of predominant current practice for large furnaces, The Hague plant is noteworthy in that the furnace sidewalls are not water-cooled. What water-tube walled surface is used begins above the furnace and extends from there upward to the top of the radiation chamber (first boiler pass). The sloping rear roof of the furnace is water-cooled but the tubes are completely covered by formed refractory block supported between the tubes. Thus, there is very little cooling of the predominantly refractory furnace. The furnace sidewall construction consists of one layer of high-alumina firebrick plus insulation and a steel casing. The full wall thickness is about 50 cm (20 in). This wall is modified alongside the drying grate where the alumina brick is replaced by silicon carbide brick to resist abrasion by the moving refuse. This refractory wall has required little maintenance in nearly ten years' operation. The refractory stops at about the level of the top of the feed opening. A horizontal header for the higher wall tubes is located at that level and the wall tubes extend upward from that level.

TABLE 9-2. DIMENSIONS OF GRATES AND RATED BURNING RATES USED AT THE HAGUE PLANT

Grate Function	Units 1-3						Unit 4					
	Length		Width		Area		Length		Width		Area	
	m	ft	m	ft	m^2	ft^2	m	ft	m	ft	m^2	ft^2
Drying	5	16.4	3	9.8	15	161	-	-	-	-	-	-
Feeding	-	-	-	-	-	-	2.5	8.2	3.4	11.1	8.5	91
Burning	5	16.4	3	9.8	15	161	6	19.7	3.4	11.1	20.4	219
Burnout	3	9.8	3	9.8	9	97	6	19.7	3.4	11.1	20.4	219
Total Grate Area					39	419					49.3	529
Rated Burning Rate (at 15 tonnes/hr each)					385 kg/m^2-hr	79 lb/ft^2-hr					304 kg/m^2-hr	62 lb/ft^2-hr
Burning Rate with only 1/2 Drying Grate					446 kg/m^2-hr	98 lb/ft^2-hr						
Burning Rate without Feed Grate											367 kg/m^2-hr	75

At first, in Units 1-3, the wall tubes in the radiation pass were bare. The tubes in Units 1-3 are 63.5 mm (2.5 in) in diameter, 4 mm (0.160 in) thick, on 85 mm (3.4 in) centers and joined by a welded fin. However, within the first year, significant wastage of the wall tubes was observed as well as in the radiant superheater suspended through the top of the radiation pass. Accordingly, that superheater was shortened by 70 cm (2.3 ft) and the wall tubes were studded with 10 mm (0.4 in) long studs and then coated with 12 mm thick (0.5 in) silicon carbide. This coating was carried up to just above the bottom of the shortened superheater.

Another unique feature of The Hague plant is that it began operation without any overfire air jets. Because of the early corrosion problems referred to earlier, sidewall jets were added. However, the plant experience is that front and rear-wall jets would be better.

At first there was little slag accumulation on the refractory sidewalls. However, in 1971 and 1972, after about three of four years' operation, thick accumulation of slag developed on the sidewalls, especially where the burning was intensified when the burning refuse dropped from the drying grate onto the burning grate. Attempts were made to remove this slag mass by means of water lances but this was deleterious to the refractory wall. The thermal shock to the hot refractory wall caused it to tilt inward. Then, continuous air injection was tried along the wall but the build-up of slag continued. It is believed that this growing problem of slag build-up was caused by a substantial rise in the heat value of Dutch community refuse in that period. The relatively high grate burning intensities calculated in Table 9-2 were contributory to the problem.

The solution to the problem of sidewall slag accumulation at that time was to reduce the load on each furnace. Instead of carrying the average daily plant load of about 700 to 750 tonnes per day in two units, each nominally rated at 360 tonnes/day (400 tons/day); the third or spare unit was brought into regular operation so that each unit had to handle only about 230 to 250 tonnes per day (260 to 275 tons/day). However, it is well established that, in this technology, normal wear and tear usually requires a plant to have one spare unit so that each unit in turn can benefit from a well-established preventive maintenance program. It appears that such considerations led, in 1971, to the order for Unit 4 which began operation early in 1974. The wisdom of this expansion is

attested by the fact, mentioned earlier, that the refractory furnace walls of Units 1-3 have required essentially no maintenance except slag removal in nearly ten years' use. Operation of Units 1-3 at reduced rate has eliminated the slag accumulations.

The annual waste input to the plant reached a peak of 229,000 tonnes in 1976. If Unit 4 had not been available that year, Units 1-3 would have been overloaded which certainly would have caused much difficulty in added maintenance costs and reduced availability. Assuming 5-1/2 days per week operation, the 229,000 tonnes burned in 1976 in 52 weeks in three units, (one spare), nominally rated at 360 tonnes/day each results in an estimated operating rate of 800 tonnes/day or 105 percent of rated capacity. Although no mention was made by plant staff of any recent return of problems from sidewall slag build-up, its imminence may have encouraged a decision to plan to install air-cooled Künstler wall blocks in Unit 2 in 1978.

It is notable that the SiC covering on the studded wall tubes requires little maintenance. During each year approximately four square meters of coating is replaced in each boiler.

Figure 9-14 shows, schematically, the arrangement of the air flow through the patented, cast steel, Kunstler blocks which will soon be added on Unit 2. Kunstler of Zurich has added this modified air-cooled wall construction to over a dozen European plants since 1972. It is also now being incorporated into some new plants as original construction. The system does appear to provide relatively cool sidewalls so that sticky slag particles that may touch it are chilled and solidified before they have time to fuse to the wall. The installation in Unit 2 at The Hague will provide an interesting test of block durability in a large, heavily-loaded furnace.

Figure 9-14a and 9-14b show a similar wall cooling system using perforated refractory blocks by Didier-Werke AG, Weisbaden, Germany, which Von Roll is now applying at other plants. The installation shown in these figures is at Solingen, West Germany.

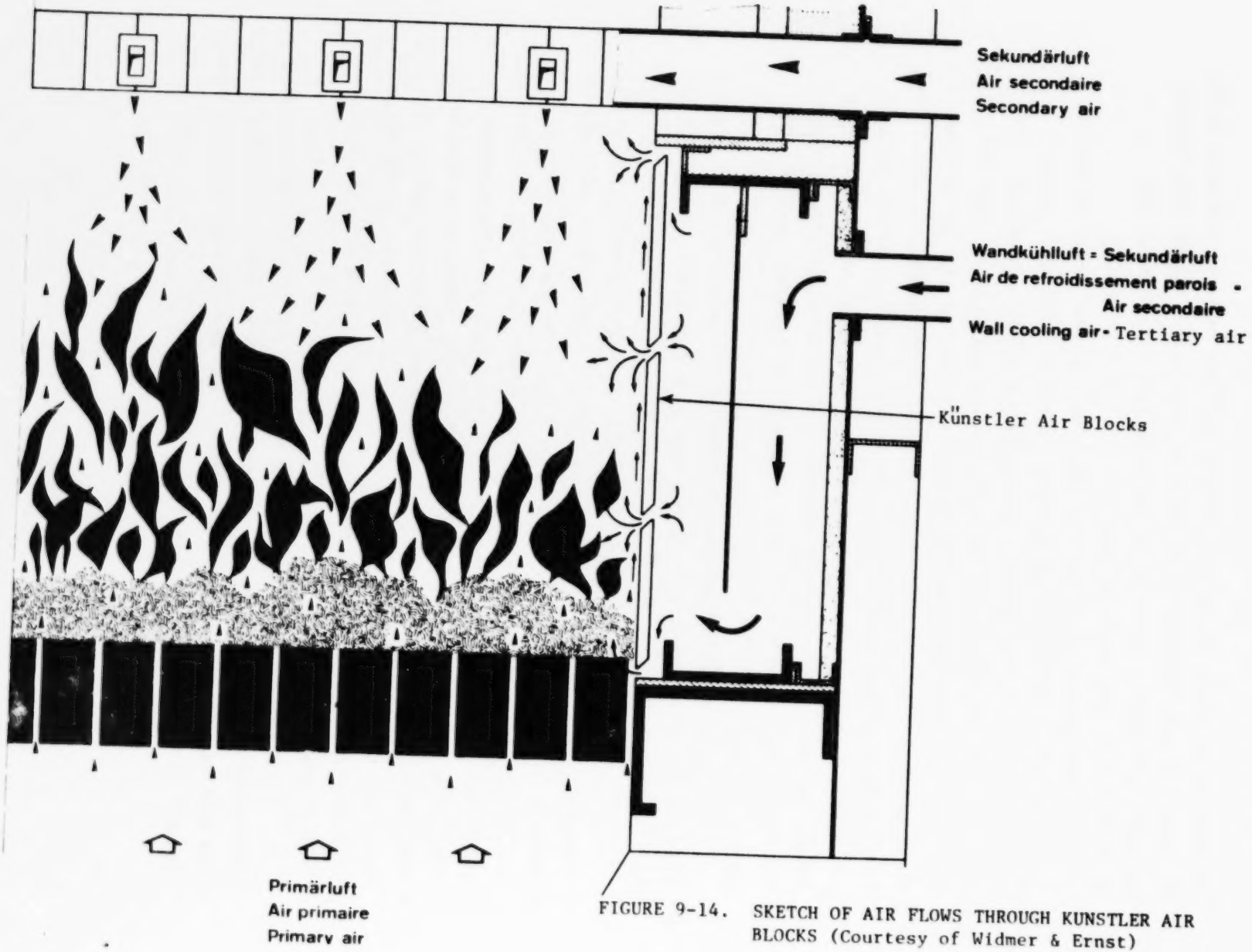


FIGURE 9-14. SKETCH OF AIR FLOWS THROUGH KUNSTLER AIR BLOCKS (Courtesy of Widmer & Ernst)

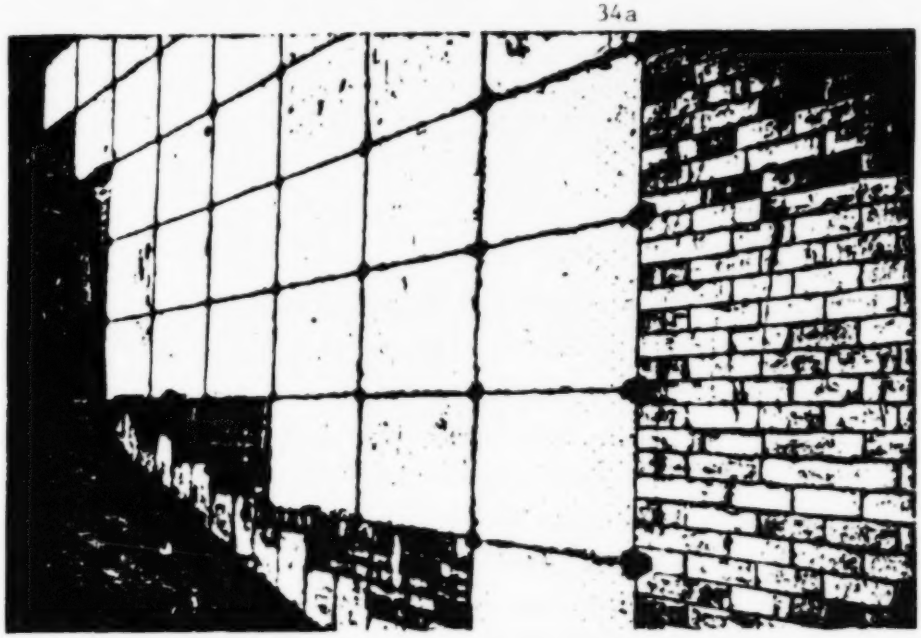


FIGURE 9-14a. PERFORATED AIR-COOLED REFRACTORY WALL BLOCKS BY DIDIER AS INSTALLED BY VON ROLL AT THE SOLINGEN PLANT, WEST GERMANY (COURTESY VON ROLL)

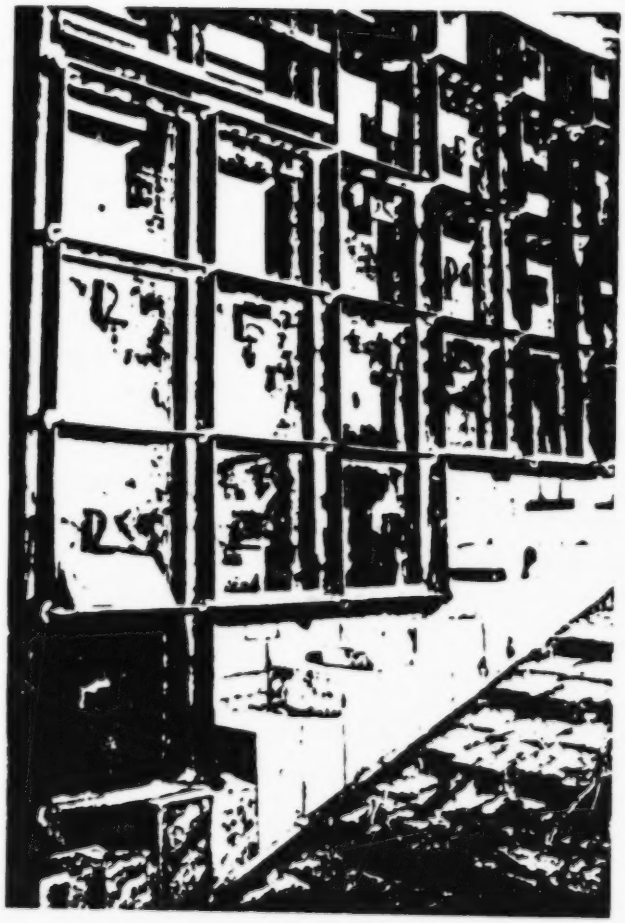


FIGURE 9-14b. CONSTRUCTION PHOTOGRAPH SHOWING AIR SUPPLY CHAM FOR THE REFRACTORY WALL BLOCKS SHOWN IN FIGURE 9-14a.

Superheater (Units 1-3)

Figure 9-15 shows the original superheater and boiler arrangement for Units 1-3, as designed in 1965. The superheater was in two sections. The first section was a platen-type radiant superheater which was inserted about 3.6 m (11.8 ft) downward from the water-cooled roof into the radiation chamber (first pass). Subsequent experience at many plants has revealed that this was a particularly vulnerable location for a superheater. The designer estimated that the flue gas temperature, as it rose in the radiation chamber toward the superheater, would be about 955 C (1751 F). With a steam temperature leaving the superheater of 425 C (797 F) the temperature of potentially corrosive chloride salts on the superheater surface could thus rise well over 500 C (932 F) both from contact by surges of high temperature flame and from intense radiation from the incandescent gases in the furnace below. Thus, in hindsight, it is not surprising that the pendant superheaters in Units 1-3 had tube wastage within the first year of operation. The solution to this attack was to shorten the platten by about 70 cm (2.3 ft) and to increase the tube thickness from 2.9 to 5 mm (0.12 to 0.2 in). After about five years and about 25,000 to 30,000 hours operation, the pendant superheater was replaced at a cost of DG 60,000 ($24,600 @ 2.44/$).

The second superheater section, a sinuous convection type, is shown in Figure 9-15 at the top of the second pass. A spray-type de-superheater (attemperator) is between the sections. The designer estimated that the gases entering the second superheater section would be about 900 C (1652 F) and leaving it would be 807 C (1485 F). In this section, corrosion was observed two or three years after startup. However, the steam temperature there is lower and the corrosion rate is apparently not rapid. This superheater section will also soon be replaced.

Superheater (Unit 4)

During the three years between 1968, when Units 1-3 were started up, and 1971, when Unit 4 was ordered, much had been learned both at this plant and elsewhere about some of the causes of superheater corrosion. One

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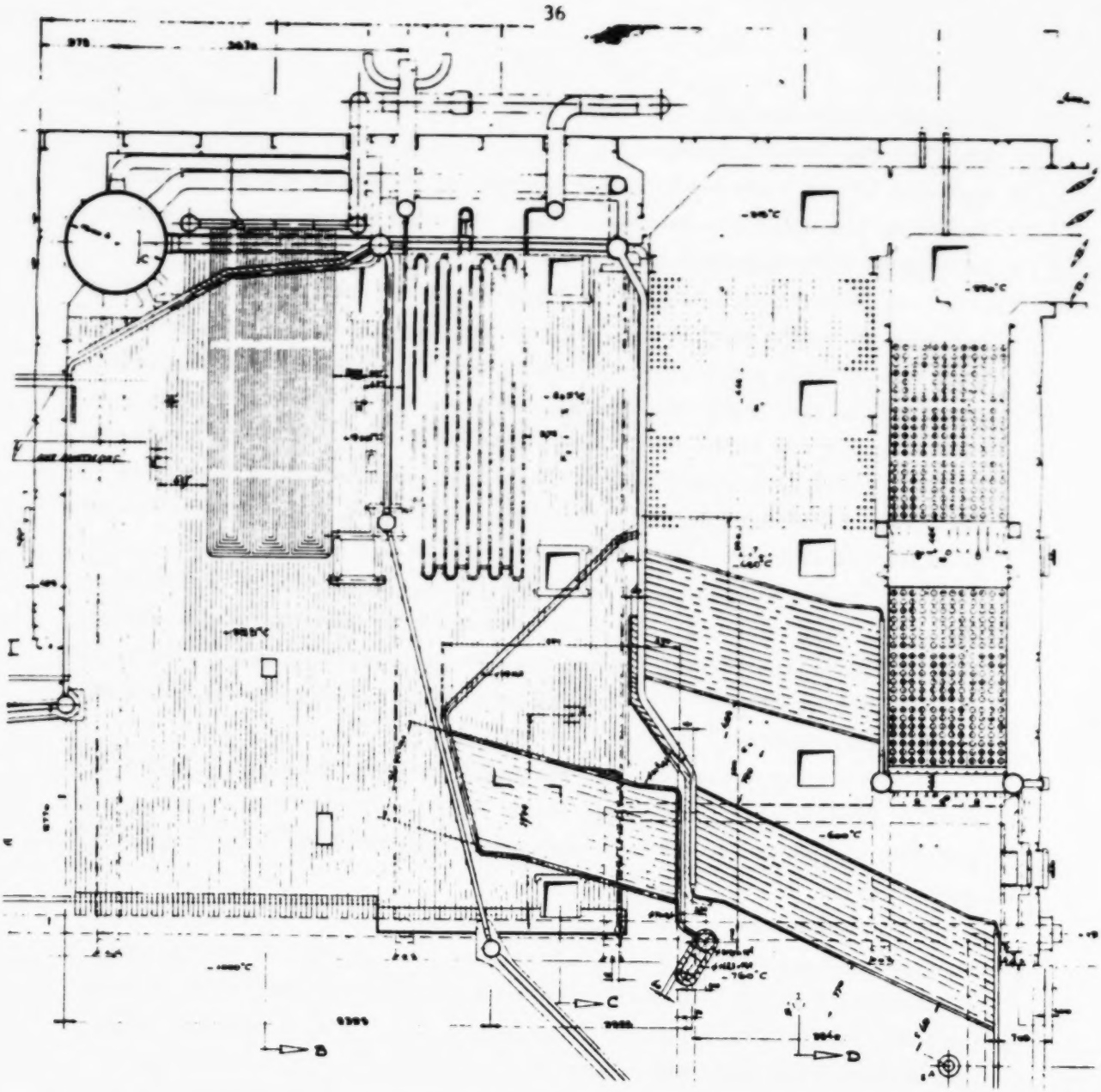


FIGURE 9-15. WATER-TUBE WALL PORTION OF BOILERS IN UNITS 1-3, THE HAGUE, SHOWING SUSPENDED PLATTEN-TYPE SUPERHEATER AT TOP OF RADIATION PASS, SCREEN TUBES AT OUTLET FROM RADIATION PASS, SINUOUS TUBE CONVECTION-TYPE SUPERHEATER AT TOP OF SECOND WATER-TUBE WALLED PASS, BOILER CONVECTION SECTIONS, ECONOMIZER, AND TUBULAR AIR HEATERS. (Courtesy of Von Roll)

emerging lesson was that the superheater should be as far removed as possible from the furnace flames. In this way any potentially corrosive chloride deposits on the tubes would not be overheated by sudden surges of flames extending far above the furnace. Also, the deposits would not be heated by intense radiation from the furnace.

Accordingly, as seen in Figure 9-13, the horizontal superheater sections in Unit 4 are far removed from the furnace. Also, the entirely open second pass, completely water-tube walled, provides cooling of the gases before they reach the first superheater section at the bottom, beginning, of the third pass. Thus, instead of an estimated gas temperature of 955 C (1751 F) approaching the pendant superheater in Units 1-3, in Unit 4 the partially cooled gas entering the horizontal superheater bundle is estimated to range from 530 to 630 C (986 F to 1166 F).

Another improvement helping to alleviate corrosive conditions was to add secondary air jets in the sidewalls in Units 1-3 and to include them in the initial design for Unit 4. These jets are located high in the refractory sidewalls of the furnace, just below the coated water-tube wall of the first (radiant) pass.

The steam flow through the first (bottom) superheater section is counter flow so that the hottest steam (425 C) [797 F] "meets" the hottest gas. In the second superheater section of Unit 4 the steam and gas flows are cocurrent.

The boiler redesign and air jets just described have eliminated superheater corrosion in Unit 4 except for some wastage in the vicinity of the soot blowers. This is being satisfactorily controlled by means of carbon steel shields covering the affected tubes. It is estimated that the shields will need replacement every four years.

In Unit 4 the superheater tubes are made of 15 Mo 3 steel, 38 mm (1.5 in) diameter and 3.6 mm (0.14 in) thick. The spacing between the in-line rows is 150 mm (5.9 in). In Units 1-3 this spacing was only 80 mm (3.1 in). With this wider spacing, it is estimated that the unit could run 8000 hours (about two years) before chemical cleaning of the tube deposits would be necessary. However, tube thickness is checked once per year, hence cleaning is needed each year before the thickness measurements are made.

At first in Unit 4 the soot blowers were operated once per shift. This caused tube erosion; hence the 20 bar (290 psia) blowers are no longer used. Instead, the entire boiler system is cleaned about every three months by a Dutch contractor: FA Conservator of Rotterdam. They use high pressure jets of a solution of sodium carbonate to clean the ash deposits from the tubes.

Boiler (Units 1-3)

The overall boiler system was built by Bronswerk Amersfoort of Holland under a license for the Eckrohr design by Dr. Vorkauf of Berlin. The boilers are designed for a steam flow range of 18.8 to 37 tonnes/hr (41,360 to 81,400 lb/hr) at 40 bar (580 psia) and 425 C (797 F). The top of the steam drum is 20.9 m (68.4 ft) above the ground floor.

As can be observed in Figures 9-13 and 9-15, the arrangement of the boiler convection tube bundles is unique in that the gas, as it flows upward out of the first inclined tube bundle at an estimated 600 C (1112 F), is divided into two streams as it continues upward in the third pass. Part of the gas flows into the second convection bundle, also inclined, and then into the economizer. The remainder flows upward through two passes of a tubular air heater. The amount of gas that flows along each path can be controlled by two sets of multiple vane dampers, one located at the outlet of the economizer and the other after the air heater. The design estimate was that the gas leaving the economizer would be about 315 C (600 F) and leaving the air heater it would at 220 C (428 F). Actually these temperatures will vary depending on the damper settings.

Boiler (Unit 4)

This boiler is slightly larger and much taller than the first three, having a steam range of 18.8 to 40 tonnes/hr (41,360 to 88,000 lb/hr). However, the maximum firing rate, 15 tonnes per hour, is the same as units 1-3. The higher rating comes from an expected higher heat value in the refuse. The top of the steam drum is 24.3 m (79.7 ft) above the ground floor.

The convection section for Unit 4 is quite different from Units 1-3 as can be seen by comparing them in Figure 9-13. The second pass is a completely open water-tube-walled down-pass with the superheater banks horizontal across the bottom of the third pass and thus far removed from the furnace. The air heater was eliminated in Unit 4 and the third pass contains not only the superheaters but also the two evaporator bundles and two tubular economizers.

Economizer

The tubular economizers have given trouble-free service except at the beginning of operation of Units 1-3, leakage developed that was caused by an error in installation which was corrected.

Air Preheater (Units 1-3)

Consistent with the design concept in 1965 that the refuse from this community would be very wet due to the rainy Holland climate and thus need special provisions for drying, tubular air heaters were installed parallel to the economizers as seen in Figure 9-13. A separate steam heated air heater using 4.3 bar (62.4 psia) steam at 146 C (295 F) was provided ahead of the tubular gas-to-air heater to help prevent condensation from the flue gases in the cold end of the tubular heaters. However, when both the steam heater and gas-to-air heaters were operating, the primary air temperature reached 300 C (572 F), and the grates became overheated. But, operation without the steam pre-heat caused dewpoint corrosion in the tubular air heaters. Furthermore, as the heat value of the community refuse increased, there became less need for drying it on the grate by means of preheated air.

Air Preheater (Unit 4)

Because of the numerous difficulties in Units 1-3 with air preheating by extracting heat from the flue gas, Unit 4 has simply a steam heated air heater using high pressure steam.

Primary Air

The primary combustion air supply for all four units is similar with a few important variations for Unit 4. Each unit is supplied with preheated air from a radial type blower made by Pollrich of Mönchengladbach, Germany. The maximum primary air pressure to Units 1-3 is 400 kg/m^2 (3930 Pa) [15.8 in w] and to Unit 4 is 365 kg/m^2 (3585 Pa) [14.4 in w]. Maximum air preheat temperature for Units 1-3 was originally 300 C (572 F) but, as explained earlier under "Air Preheater" this involved various difficulties and now, using steam-heated heat exchangers only, the primary air is heated to about 80 C (178 F). On Unit 4 steam is used to heat the primary air to 150 C (302 F).

The air is supplied to the grate in six or seven zones, each controlled by a manually set damper.

Because of the dust content in the primary air which is drawn from near the top of the main refuse bunker, a 1 mm (0.040 in) thick deposit of dust builds up on the blowers each year. The deposit is removed once per year by means of high pressure water jets at 350,000 kg/m^2 (500 psi) [3433 kPa] and 90 C (195 F).

The induced draft fan accumulates deposits much faster, hence, it is similarly washed for two hours every three weeks.

Secondary Air

Furnaces 1-3 were originally installed without secondary air jets. This was consistent with the original design concept for this plant which was expected to be faced with the problems of burning high-moisture, low-calorific-value waste. Thus, the potential cooling effect of secondary air jets was probably deemed of greater disadvantage than any gain that would accrue from the mixing action of the air jets.

However, as pointed out in the discussion of wall-tube and superheater corrosion, within the first year of operation, wastage of both areas was observed and it was concluded that the temperatures in the radiation pass (first pass) were, at times, excessive. Accordingly, after one year's operation, nine secondary air jets were added on each side of each of Furnaces 1-3. They are about 50 mm (2 in) diameter and are located in one horizontal row in the refractory sidewall just below the beginning of the water-tube wall of the radiation pass. The jets are supplied with a maximum of 21,000 Nm^3/h (12348 scfm) biler room air by a radial blower producing a maximum static pressure of 390 mm (3834 Pa) [15.4 in w].

When Unit 4 was built, it was supplied with a similar horizontal row of nine jets on each side close to the main burning grate. Figure 9-16 shows the secondary air manifold on the side of Furnace 4. In addition to the ten jets in the horizontal row there are two additional jet tubes visible on a sloping line at the left. These are probably directly above the step in the grates between the feed grate and the main burning grate with the slope of the line of jets conforming approximately to the slope of the angle of repose of the refuse as it flows into the furnace. A useful detail of the jet tubes shown in Figure 9-16 is that each tube is lightly capped by a spring-loaded cover which can be easily lifted aside for inspection of the jet and, if the jet entry into the furnace is observed to be clogged by ash or slag, the buildup can be readily poked into the furnace by means of a rod inserted through the tube.

It is not clear whether the addition of these secondary air jets was beneficial. The plant staff appeared to prefer future application of front-wall and rear-wall jets in view of the predominant experience elsewhere that such jets appear to provide better mixing.

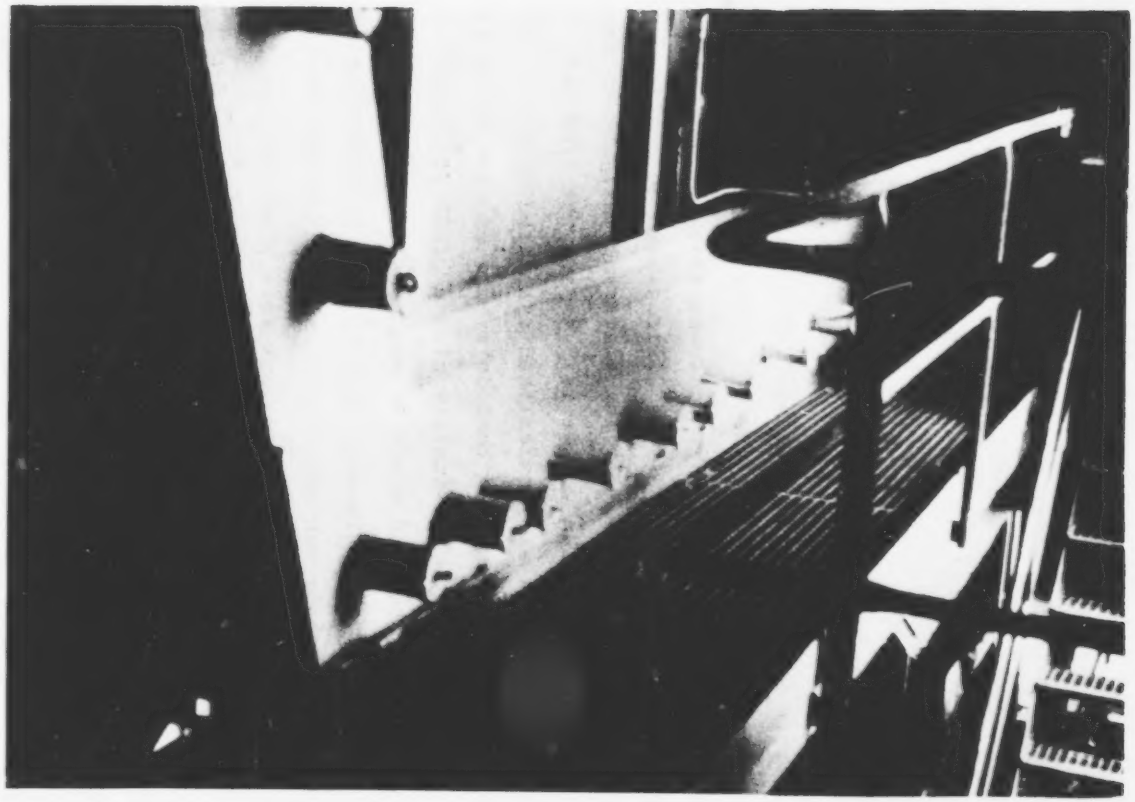


FIGURE 9-16. EXTERIOR VIEW OF TUBES FOR SECONDARY AIR JETS ON SIDE OF UNIT 4. TEN JETS ARE SPACED HORIZONTALLY AND TWO ARE LOCATED ALONG A SLANTING VERTICAL LINE AT LEFT. NOTE SPRING-LOADED CAP ON EACH TUBE TO FACILITATE INSPECTION AND CLEANING (Battelle Photograph)

As has been described earlier under Furnace Wall, the walls of Unit 2 will shortly be modified to incorporate Künstler air-cooled wall blocks as shown in Figure 9-17. Presumably, this method of introducing low-velocity secondary air will replace the present wall jets. That furnace may then once more be operating without the mixing action of moderate-velocity air jets. Whether this lack will affect furnace performance remains to be seen.

Heat Release Rate

An estimate has been made in Table 9-3 of the combustion volumes and burning and heat release rates in the two types of boiler-furnaces in this plant. To estimate combustion volume it was assumed that combustion is complete when it reaches the top of the Silicon Carbide-coated walls of the radiation pass (first pass). If the flames normally never reach that high then the true combustion volume is less and the true heat release rates are actually somewhat greater than estimated here.

For Units 1-3 it is assumed that only half of the drying grate is active with combustion, or approximately 31.5 m^2 (339 ft^2) total burning area. For Unit 4 the feed grate is not considered as combustion surface leaving a total of approximately 40.5 m^2 (439 ft^2) burning area. In all cases combustion volume was considered only that volume vertically above active grate area. The grate dimensions were given earlier in Table 9-1.

The conditions indicated by the estimated rates in Table 9-3 are that the initially designed grate burning rate for Units 1-3 of 476 kg/m^2-hr (97.3 lb/ft^2-hr) was rather high, but that with 1800 kcal/kg heat value of the refuse, the heat release rates on the grate and in the furnace were moderate. Even when the heat value rose to 2300 kcal/kg the heat release rates were not excessive. On the other hand, Unit 4, with a larger furnace (combustion volume) and a much larger effective grate, was much more conservatively designed. In addition, in Unit 4 the superheater was not placed at the top of the radiation pass but was moved

TABLE 9-3. ESTIMATED COMBUSTION RATES AT THE HAGUE

	Unit 1-3	Unit 4
Year Unit began operation	1968	1974
Combustion Volume, m^3	232	258
Combustion Volume, ft^3	8192	9110
Grate area, m^2	31.5	40.8
Grate area, ft^2	339	439
Burning Rate:		
Per boiler, tonnes/hr	15	15
Per boiler, tons/hr	16.5	16.5
Total Heat Release per Boiler, Gcal/hr		
at 1800 kcal/kg (3240 Btu/lb)	27	27
at 2300 kcal/kg (4140 Btu/lb)	34.5	34.5
Grate burning rate, kg/m^2-hr	476	367
Grate burning rate, lb/ft^2-hr	97.3	75.2
Grate heat release (at 1800 kcal/kg) $kcal/m^2$-hr	856,800	660,000
Grate heat release (equiv), Btu/ft^2-hr	315,252	243,648
Grate heat release (equiv), MJ/m^2-hr	3,587	2,766
Grate heat release (at 2300 kcal/kg) $Kcal/m^2$-hr	1,094,800	844,100
Grate heat release (equiv), Btu/ft^2-hr	402,822	311,328
Grate heat release (equiv), MJ/m^2-hr	4,584	3,534
Volume heat release (at 1800 kcal/kg) $kcal/m^3$-hr	116,379	104,651
Volume heat release (equiv), Btu/ft^3-hr	13,052	11,736
Volume heat release (equiv), MJ/m^3-hr	487	438
Volume heat release (at 2300 kcal/kg) $kcal/m^3$-hr	148,707	133,721
Volume heat release (equiv), Btu/ft^3-hr	16,677	14,997
Volume heat release (equiv), MJ/m^3-hr	623	560

beyond the second radiation pass to the third (convection) pass. This, too was a much more conservative design policy. As a consequence it is not surprising that Unit 4 has suffered none of the corrosion problems that came to Units 1-3 from probable overheating of the potentially corrosive deposits on the wall tubes and superheaters.

Boiler Water Treatment

The waste-burning plant receives its treated makeup water from the adjacent 200 mw municipal power plant. It is fully demineralized and deoxidized.

Start-up Procedure

The Von Roll organization provides each plant with a detailed operating guide including specific procedures for startup to avoid overheating and damage to the system. At this plant the operator is also required to follow established curves showing the rate of rise of furnace temperature, economizer outlet temperature, and steam flow rate. Throughout the period of startup of a unit which normally will take 18-24 hours the operator plots the critical parameters on a startup chart so that the active curve for each parameter is plotted alongside the prescribed startup curve which has been established from experience. Thus, the startup chart serves as a guide to the operator and, when completed, provides a record of any excursions that may have occurred during the process. This is one more indication of careful management at this plant that is reflected in relatively low maintenance and operating costs.

ENERGY UTILIZATION EQUIPMENT

The energy available from this plant is electrical only. Internally, a small amount of steam at 4.3 bar (62 psi) [427 kPa] is extracted from the turbines for use in plant water heating and space heating. The electricity is generated in two 11.5 Mw 10,000 volt condensing turbogenerators operating at 40 bar (580 psia) [4000 kPa]. About 15 percent of the power generated in 1975 was used internally. The remainder was supplied to the municipal network which is supplied principally by the large oil-fired power plant just across the Afvoer Canal from the waste plant. Because there is always ample cooling water available in the adjacent canal, the condensers are water cooled. There are, however, some plans to eventually use the turbine exhaust heat in the adjacent community.

During weekdays the contract with the municipal electrical organization requires the waste plant to generate for distribution at least 5.5 Mw between the hours of 6:00 a.m. and 10:00 to 11:00 p.m. If production falls below that level the waste plant loses a bonus of DG 30,000 per month ($12,300@ 2.44/$). Accordingly, considerable attention is given to preventive maintenance throughout the plant to enable reliable operation. The plant, as a whole, achieves 74 to 76 percent availability.

POLLUTION CONTROL EQUIPMENT

Each unit is equipped with an electrostatic precipitator. Those for Units 1-3 were made by a Swedish company. No. 4 was built by Rothemühle of West Germany. Gas flow rate is 90,000 Nm^3/h (52,965 scfm).

There are two electrical fields per precipitator. Preliminary model flow tests were made for the Unit 4 precipitator only. Average velocity is 2 m/sec (6.5 fps). Entering flow is distributed across the passage by a perforated plate. There are 204 plates per field, each 7 m by 0.3 m (23 ft by 1 ft). Plate spacing is 0.3 m (1 ft). Cleaning of the plates is by mechanical rapping. Rectifier output is 40,000 volts at 50 ma.

The pyramidal flyash hoppers for Units 1-3 are covered with 15 cm (6 in) of insulation but are unheated. The hopper for Unit 4 is heated electrically. The collected ash is sluiced to the flyash setting tank shown at the right in Figure 9-7.

The precipitators for Units 1-3 were guaranteed to achieve an emission level of 100 mg/Nm^3 (0.0437 grn/scf) corrected to 7% CO_2. They have been tested twice in ten years. The last test showed an emission of only 55 mg/Nm^3 (0.024 grn/scf). Unit 4 was guaranteed for 80 mg/Nm^3 and in September 1974, when tested emitted only 19 mg/Nm^3 (0.008 grn/scf). Its efficiency was stated to be 99.6% with two fields and 85% with one field.

As has been explained under Furnace Wall and Superheater, the refuse burned in Units 1-3 had a much higher heat value than expected with the result that there were times when the gases leaving the economizers were as high as 330-350 C (626-662 F), far above the safe operating temperature for the precipitators. As a result, the plates rapidly corroded and had to be replaced. Because of that experience the temperature entering the precipitators is now held below 270-280 C (518-536 F). When the economizer exit temperature begins to exceed about 225 C (437 F) plans are made to clean the boiler heating surfaces. These practices have almost eliminated plate corrosion.

Chimney

The two concrete stacks, 100 m (328 ft) tall are brick lined. The inside diameter of the outer shell is 5 m (16.4 ft). The liner is 2.7 m (8.9 ft) inside.

Between the stack wall and liner is space to permit annual inspection and repair. Some major cracks needed repair after six years operation.

Wastewater Discharge

There is no wastewater discharge from the plant except sanitary wastes and moisture in the quenched residue and sluiced flyash.

Noise

The plant is completely enclosed and except for the barely noticeable sound of trucks coming and going is not a source of annoying noise to the numerous nearby residents. Dutch regulations permit no more than 45 decibels at the plant boundary day and night.

Residue Processing

Until very recently, the quenched furnace residue and wet flyash have been hauled to the Rijswijk landfill without any processing for resource recovery. However, in August 1977 the processing equipment shown in Figure 9-17 was installed adjacent to the plant by a private company which evidently hopes to benefit from resource recovery. The magnetically separated steel scrap piled in the foreground is to be sent to a steel plant. The conical pile of sized cinders in the background will be used for fill and road building. This processing plant is too new to have produced any data on its costs and revenues.

FIGURE 9-17. CONVEYORS AND MAGNETICALLY SEPARATED SCRAP AND PILE OF SIZED RESIDUE ACCUMULATED BY NEW RESOURCE RECOVERY SYSTEM ADJACENT TO THE HAGUE PLANT (Battelle Photograph)

POLLUTION CONTROL ASSESSMENT

The location of this plant, as illustrated in Figure 9-4, close to the center of this city surrounded by quiet row housing has naturally imposed a severe requirement that its operation be nuisance-free. The plant presents a very clean appearance and the stack emissions are only slightly visible. Emission tests reported earlier were well within the allowable limits. Very little wastewater is discharged.

EQUIPMENT PERFORMANCE ASSESSMENT

In 1976 the plant produced 85,028,300 kw-hr, 71,930,500 kw-hr of which was delivered to the municipal electric system, thus earning, at DG 0.03/kw-hr, DG 2,157,915 ($884,391@ 2.44/$). To achieve this performance the two 11.5 mw steam turbogenerators operated 5710 and 5698 hours respectively, and average overall plant availability for generating of 82.9% based on a 5.5 day week of operation (6883 hr/yr). As explained earlier, good plant reliability is achieved by having one of the four units available for repair and preventive maintenance.

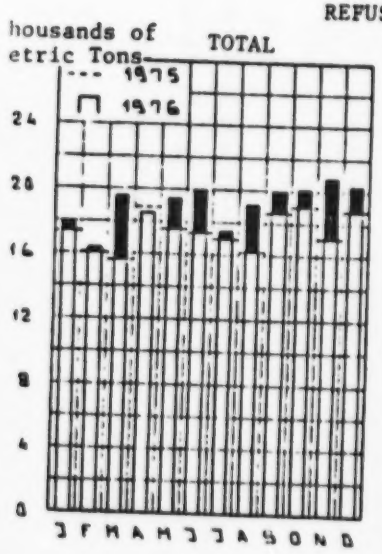
Of the total energy delivered, 35.7×10^6 kw-hr was delivered during the days, 36.2×10^6 kw-hr at night. Maximum 5-minute average peak production rate was 19,160 kw at 2:25 p.m. on December 10, 1976.

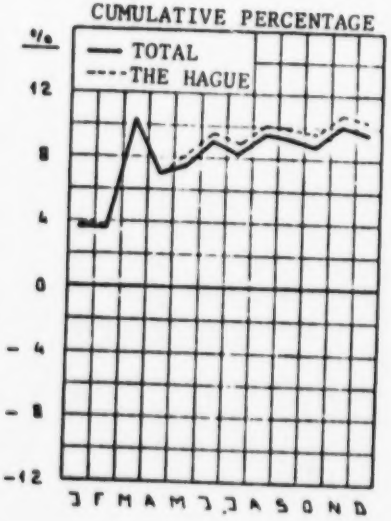
Table 9-4 shows an annual summary sheet prepared by the staff each year to depict overall plant performance. In that table the final chart and the final column both have to do with the electrical contract with the parent organization, Gemeentelijk Energiebrijf (municipal utility). That contract provides a monthly bonus if the waste plant delivers at least 5.5 mw continuously during the 5.5 days of operation each week. Table 9-4 shows that in 1976 that monthly bonus was won in all months except April, August, and October because on a total of 26 days the minimum rate was not maintained.

In addition to the annual plant performance tabulation, every month the staff produces a monthly summary of availability of all major plant components showing for each boiler-furnace, turbine, crane, and

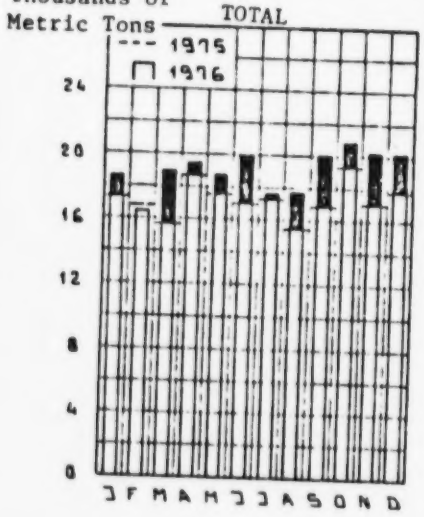
TABLE 9-4. REFUSE BURNING SUMMARY, THE HAGUE, 1976 (COMPARED TO 1975)

REFUSE DELIVERED

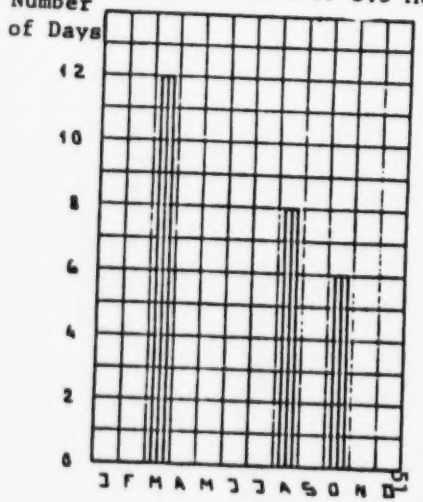




REFUSE BURNED



DAYS PER MONTH WHEN OPERATED BELOW CONTRACTEI GENERATED RATE OF 5.5 MW



	REFUSE DELIVERED							REFUSE BURNED	
	The Hague		Suburbs		Percent of Annual Deliv.				
	1975	1976	1975	1976	The Hague	Suburbs	Total	1975	1976
	Tonne	Tonne	Tonne	Tonne	%	%	%	TON	TON
JANUARI	15 770	16 379	1 585	1 601	3.9	1.0	3.6	17 285	18 605
FEBRUARI	30 274	31 356	3 812	3 074	3.7	2.0	3.6	34 112	35 067
MAART	44 569	49 236	4 479	4 865	10.4	8.6	10.5	49 990	54 088
APRIL	61 772	66 100	6 220	6 580	7.0	5.8	6.9	68 651	73 573
MEI	77 499	83 757	8 035	8 328	8.1	3.7	7.6	86 221	92 390
JUNI	93 099	101 922	9 701	10 111	9.5	4.2	9.0	103 100	112 264
JULI	108 123	117 728	11 460	11 719	8.9	2.3	8.2	120 417	129 516
AUGUSTUS	122 721	135 182	12 996	13 434	10.1	3.4	9.5	135 903	147 650
SEPTEMBER	139 557	153 342	14 686	15 196	9.9	3.5	9.2	154 084	167 781
OKTOBER	156 765	171 614	16 468	16 971	9.5	3.1	8.8	173 357	188 590
NOVEMBER	172 259	190 664	18 038	18 745	10.7	3.9	10.0	190 391	208 848
DECEMBER	189 387	209 187	19 877	20 488	10.4	3.1	9.7	208 262	229 099

	ELECTRICAL ENERGY PRODUCED			
	NET POWER DELIVERED		5 Min.	Days under
	Monthly	Cumulative	Peak Gen.	< 5.5 mw
	MWh	MWh	MW	Days
JANUARI	5 695	5 695	17.88	-
FEBRUARI	4 812	10 507	16.40	-
MAART	6 241	16 748	17.64	12
APRIL	6 624	23 372	17.60	-
MEI	6 675	30 047	17,64	-
JUNI	6 380	36 427	16.60	-
JULI	5 698	42 125	16.68	-
AUGUSTUS	5 618	47 743	15.36	8
SEPTEMBER	6 004	53 747	15.48	-
OKTOBER	5 298	59 045	13.68	6
NOVEMBER	6 200	65 245	17.88	-
DECEMBER	6 686	71 931	19.16	-

pump the period of operation, time required for maintenance, repair, or modification. Also, a hand-recorded daily table is included showing, by coded symbols, which days of the month which components did or did not operate and why. Thus, management can tell at a glance over several months of these coded tables which particular components are trending toward decreasing availability and hence should receive appropriate maintenance.

Table 9-5 shows the annual plant performance results for the seven years 1970-1976. The most notable item in this extensive record is steam produced, tonnes per tonne of refuse. Although this plant, as all waste-to-energy plants, must contend with a highly variable source of energy, it shows a remarkably consistent production rate. That rate ranged for 1.92 to 2.02, a maximum variation over seven years of $\pm$ 2.5%. The decided drop in rate in 1974 is attributed to the severe energy crisis caused by the Arab oil embargo beginning in October 1973. Plant staff surmised that many householders found ways to reduce the amount of combustible materials discarded.

TABLE 9-5. THE HAGUE PLANT ANNUAL OPERATING RESULTS OVER SEVEN YEAR PERIOD. (FURNACE 4 BEGAN OPERATION EARLY 1974)

	*	1970	1971	1972	1973	1974	1975	1976
Operating Personnel								
Day Shift Personnel		16	17	18	18	18	20	21
Shift Personnel		33	33	34	34	33	33	33
Total		49	50	52	52	51	53	54
Combustion								
Refuse	t	190,696	197,838	216,787	202,668	206,847	208,100	229,099
Residue								
Clinker	t	70,462	76,781	78,900	72,687	72,694	73,805	83,917
Scrap Metal	t	--	--	--	--	--	--	1,361
Operating Time								
Per furnace	h						4,657	5,687
							4,385	4,886
							4,819	5,224
							4,972	4,688
Total of all furnaces	h	15,601	16,797	18,817	17,606	16,665	18,833	20,485
Steam								
Steam Production	t	366,257	383,249	432,869	406,489	397,707	419,823	454,152
Steam Production/t Refuse	t	1.92	1.94	1.99	2.01	1.92	2.02	1.98
Steam Delivery	t	--	--	409,176	385,282	375,000	--	--
Power								
Power Consumption x 1000	kWh	9,922	10,356	11,984	11,465	10,860	11,392	13,098
Power Consumpt./t Refuse	kWh/t	52.0	52.4	55.3	56.6	52.50	54.74	57.17
Power Production x 1000	kWh	70,716	71,904	81,835	77,056	69,661	76,803	85,028
Power Production/t Steam	kWh/t	193.08	187.62	189.05	189.58	175.16	182.94	187.22
Power Delivery x 1000	kWh	60,793	61,548	69,852	65,591	58,741	65,411	71,931
Water Consumption								
Total Water Consumption	m^3	1,452,692	1,445,728	1,476,030	1,500,672	1,285,507	1,419,736	1,500,901
City Water	m^3	182,249	178,144	3,650	3,972	3,307	3,616	4,002
Industrial Water	m^3	1,252,250	1,246,360	1,296,700	1,321,500	1,086,000	1,232,700	1,367,485
Water Consumpt./t Refuse	m^3/t	7.62	7.31	6.80	7.40	6.21	6.82	6.55
Well Water	m^3	--	--	175,680	175,200	175,200	162,000	--

*Metric Units.

PERSONNEL AND MANAGEMENT

The plant was built by the city and is under the overall management of the Director of Utilities who also oversees the operation of the adjacent 200 Mw power plant and gas and district heating facility. That combined facility has a staff of 1500 workers. The refuse plant has a staff of 54. However, major repairs of the refuse plant are handled by the maintenance staff from the main power plant. Mr. Postma, plant manager, gives a report each day on his plant's operation to the manager of the utilities plant.

The plant staff numbers 54, including the manager and assistant manager. There are 33 operating personnel divided over four shifts as follows:

- 4 mechanics
- 4 machinist-turbines
- 4 boiler operators
- 4 crane operators
- 8 relief mechanics
- 4 laborers
- 5 reserve shiftworkers
- 2 slag crane operators
- 2 electricians
- 2 meter and control technicians
- 3 pipefitters
- 2 operators for hospital refuse burner
- 1 janitor <7 outside maintenance staff

The work week is 40 hours. All jobs are described in available plant records.

The key staff all have marine experience: the chief engineer- 10 to 15 years, the assistant engineers- 8 to 10 years.

Attainment of a marine chief engineer's status in the Netherlands requires:

- 12 years through high school
- 2 years marine school
- 1 year at sea
- 3/4 year training as third class engineer
- 2 years at sea
- 1 year training as second class engineer
- 3 years at sea
- 1-1/2-2 years training as chief engineer

Although marine training is obviously not crucial to the operation of a waste-burning power plant, this type and extent of experience is essential in preparing the principal operating staff for successfully coping with the problems of waste handling and burning.

ENERGY MARKETING

The refuse plant receives DG 0.03/kw-hr ($0.012/kw-hr@ 2.44/$) from the city utility department of which it is a part. Thus, if both turbines are operating to produce a total of 23 Mw, the income would be DG 690/hr ($282.79/hr@ 2.44/$). If a base supply rate of 5.5 Mw is maintained throughout a month the plant is paid an additional bonus of DG 30,000 ($12,295.08). If this minimum energy delivery rate cannot be maintained the bonus is lost for that month.

ECONOMICS

The capital cost for the plant as it stands today, not including land cost, was DG 62 million ($15.5 million in terms of 1969 guilders at 4.00/$). However, this included Units 1-3, built in 1967-68, and the entire building for DG 45 million plus Unit 4 added within that building in 1972-74 at a cost of DG 17 million.

At present, the approximate amortization cost is DG 28/tonne of refuse fired ($10.43/ton @ 2.44/$). This and other operational charges for 1976 were as follows:

	Guilders/tonne	$/ton
Principal and interest	28.0	10.43
Maintenance	16.5	6.15
Operation	10.0	3.73
Water use and ash disposal	3.0	1.12
Total cost	57.5	21.43
Revenues are:		
Sale of electricity	15.0	5.59
Tipping fee (The Hague)	6.3	2.35
Tipping fee (Suburbs)	3.0	1.12
Total Revenue	24.3	9.06
Net Cost	33.2	12.37

The net waste generation per inhabitant per year is estimated to be 417 kg or 0.417 tonne (917 lb). Thus the per capita cost of disposal is DG 13.84 per year ($5.67/yr per capita). This is a relatively low figure compared to most large cities. It reflects good management, reliable equipment, and a very alert and busy staff.

FINANCE

All of the funds needed to build the plant were borrowed by the city on a 25-year loan with uniform payment and declining balance. The equipment life is estimated at 25 years, building at 40 years.

REFERENCES

1. Vuilverbranden in 's-Gravenhage, Dedicatory brochure for The Hague plant published March, 1968.

CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiply by
feet	meters	0.3048
square feet	square meters	0.0929
cubic feet	cubic meters	0.0283
inches	millimeters	25.4
cubic yards	cubic meters	0.7646
barrels (oil)	cubic meters	0.15899
miles	kilometers	1.609
square miles	square kilometers	2.589
acres	square kilometers	0.004047
acres	hectares	0.4047
gallons	cubic meters	0.003785
ton (short)	tonne (metric)	0.9078
pounds	grams	454
grains	grams	0.0648

To Convert From	To Get	Multiply by
meters	feet	3.281
square meters	square feet	10.76
cubic meters	cubic feet	35.31
millimeters	inches	0.0394
cubic meters	cubic yards	1.308
cubic meters	barrels (oil)	6.290
kilometers	miles	0.6214
square kilometers	square miles	0.3861
square kilometers	acres	247.1
hectares	acres	2.471
cubic meters	gallons	264.2
tonne (metric)	ton (short)	1.102
grams	pounds	0.002046
grams	grains	15.42

Revised Dec. 78

CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiply by
pounds per million Btu	nanograms per Joule	499.2
pounds per million Btu	milligrams per megajoule	499.2
cubic feet per minute	cubic meters per hour	1.699
gallons per minute	liters per minute	3.785
pounds per square foot	kilograms per square meter	703.1
pounds per square inch	kilograms per square centimeter	0.07031
pounds per square inch	atmospheres	0.0681
pounds per square inch	newtons per square meter	6894.8
pounds per square inch	kilopascals	6.8948
atmospheres	bars	1.0133
atmospheres	kilopascals	101.3
pounds per square inch	bars	0.06895
inches of water	pascals	249.08
millimeters of water	pascals	9.806

To Convert From	To Get	Multiply by
nanograms per Joule	pounds per million Btu	0.0023
milligrams per megajoule	pounds per million Btu	0.00233
cubic meters per hour	cubic feet per minute	0.588
liters per minute	gallons per minute	0.264
kilograms per square meter	pounds per square foot	0.001422
kilograms per square centimeter	pounds per square inch	14.223
atmospheres	pounds per square inch	14.69
newtons per square meter	pounds per square inch	0.00014
kilopascals	pounds per square inch	0.1450
bars	atmospheres	0.9869
kilopascals	atmospheres	0.0098
bars	pounds per square inch	14.50
pascals	inches of water	0.004015
pascals	millimeters of water	0.102

CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiply by
Btu	kilocalorie	0.252
MBtu	Gcal	0.252
Btu	kilowatt-hours	0.000293
Btu	Joules	1055.1
Btu per pound	kilocalories per kilogram	0.5555
Btu per pound	Joules per kilogram	2326
Btu per hour	watts	0.29307
Btu per sq ft-hr	kilocalories per sq meter-hr	2.711
Btu per cu ft-hr	kilocalories per cu meter-hr	8.897
pounds per 1000 pounds(gas)	grams per cu meter	1.205
grains per cu ft (68 F)	grams per cu meter (20 C)	2.28

To Convert From	To Get	Multiply by
kilocalorie	Btu	3.968
Gcal	MBtu	3.968
kilowatt-hours	Btu	3414
Joules	Btu	0.000948
kilocalories per kilogram	Btu per pound	1.8
Joules per kilogram	Btu per pound	0.00430
watts	Btu per hour	3.413
kilocalories per sq meter hr	Btu per sq ft-hr	0.3688
kilocalories per cu meter-hr	Btu per cu ft-hr	0.112
grams per cu meter (gas)	pounds per 1000 pounds	0.93
grams per cu meter (20 C)	grains per cu ft (68 F)	0.43

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TABLE EXCHANGE RATES FOR SIX EUROPEAN COUNTRIES,
(NATIONAL MONETARY UNIT PER U.S. DOLLAR)
1948 TO FEBRUARY, 1978(a)

	Denmark Kroner (D.Kr.)	France Francs (F.Fr.)	W. Germany Deutsch Mark (D.M.)	Netherlands Guilders (Gl.)	Sweden Kronor (S.Kr.)	Switzerland Francs (S.Fr.)
1948	4.810	2.662	3.333	2.653	3.600	4.315
1949	6.920	3.490	4.200	3.800	5.180	4.300
1950	6.920	3.499	4.200	3.800	5.180	4.289
1951	6.920	3.500	4.200	3.800	5.180	4.369
1952	6.920	3.500	4.200	3.800	5.180	4.285
1953	6.920	3.500	4.200	3.786	5.180	4.288
1954	6.914	3.500	4.200	3.794	5.180	4.285
1955	6.914	3.500	4.215	3.829	5.180	4.285
1956	6.914	3.500	4.199	3.830	5.180	4.285
1957	6.914	4.199	4.202	3.791	5.173	4.285
1958	6.906	4.906	4.178	3.775	5.173	4.308
1959	6.908	4.909	4.170	3.770	5.181	4.323
1960	6.906	4.903	4.171	3.770	5.180	4.305
1961	6.886	4.900	3.996	3.600	5.185	4.316
1962	6.902	4.900	3.998	3.600	5.186	4.319
1963	6.911	4.902	3.975	3.600	5.200	4.315
1964	6.921	4.900	3.977	3.592	5.148	4.315
1965	6.891	4.902	4.006	3.611	5.180	4.318
1966	6.916	4.952	3.977	3.614	4.180	4.327
1967	7.462	4.908	3.999	3.596	5.165	4.325
1968	7.501	4.948	4.000	3.606	5.180	4.302
1969	7.492	5.558	3.690	3.624	5.170	4.318
1970	7.489	5.520	3.648	3.597	5.170	4.316
1971	7.062	5.224	3.268	3.254	4.858	3.915
1972	6.843	5.125	3.202	3.226	4.743	3.774
1973	6.290	4.708	2.703	2.824	4.588	3.244
1974	5.650	4.444	2.410	2.507	4.081	2.540
1975	6.178	4.486	2.622	2.689	4.386	2.620
1976	5.788	4.970	2.363	2.457	4.127	2.451
1977	5.778	4.705	2.105	2.280	4.670	2.010
1978 (Feb.)	5.580	4.766	2.036	2.176	4.615	1.987

(a) Exchange Rate at end of period.

Line "ae" Market Rate/Par or Central Rate.

Source: International Financial Statistics: 1972 Supplement; April, 1978, Volume XXXI, No. 4, Published by the International Monetary Fund.